Maryland's Lower Eastern Shore

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Maryland Lower Eastern Shore Basin Characteristics

The Maryland Lower Eastern Shore basin drains 2,256 square miles. This area includes all of Wicomico County and portions of Caroline, Dorchester, Somerset, and Worcester Counties as well as areas in Delaware (Figure LE1). The basin lies in the Coastal Plain province. This basin includes the Nanticoke, Wicomico, Manokin, Pocomoke, and Big Annemessex Rivers, as well as Fishing Bay, Tangier Sound, and Pocomoke Sound.

The Lower Eastern Shore had a 2000 census population of 139,000 people in Maryland. Major population centers include Salisbury, MD, Seaford, DE, Pocomoke City, MD, Fruitland, MD, and Laurel, DE.

The Lower Eastern Shore of the Chesapeake Bay in Maryland is a predominantly forested and agricultural area. The dominant land use in the basin is forested land and wetlands, which comprise 61 percent of the Lower Eastern Shore. Agricultural land is the second largest fraction at 32 percent. Urban land comprises a small percentage of the basin's area (6 percent).

About one third of the Lower Eastern Shore is in agricultural land. A number of best management practices have been planned to help reduce non-point source pollution. Implementation of animal waste management plans, nutrient management plans, conservation tillage, treatment of highly erodible land, forest conservation and buffers, marine pumpouts, and structural shore erosion control and erosion and sediment control are all making good progress toward Tributary Strategy goals. For other issues, such as stormwater and urban nutrient management, cover crops, tree plantings and non-structural shore erosion control, progress has been slower.

Urban land comprises the smallest portion of the basin (6 percent). Of this urban land, 67 percent is considered low intensity development. 28 percent of the urban land is classified as commercial development. Only 6 percent of the area's urban land is high intensity.

The majority of the area's housing is in rural areas (72 percent), while about 25 percent is urban. As a result, only about 40 percent of the basin's housing utilizes municipal water and sewage. Point source pollution is not a major issue in this basin, despite the presence of 10 major wastewater treatment facilities and a number of minor facilities as well. Biological Nutrient Removal (BNR) has only been implemented at two of these facilities, although plans are in place for another five BNR systems by 2005. Appendix A contains graphs of average monthly nutrient loads from the basin's major wastewater treatment facilities.

As of 2002, the largest contributor of nitrogen to the Lower Eastern Shore was agricultural sources (60 percent) (Figure LES4). Point sources contributed 12 percent, forested land 11 percent, mixed open land 9 percent, and urban sources only 5 percent of the basin's nitrogen load. For phosphorus, the basin's largest contributor was also agricultural sources (58 percent) (Figure LES5). Mixed open land accounted for 19 percent of the basin's phosphorus load, point sources 10 percent, and urban sources 9 percent. For total suspended solids, agricultural sources were again the major contributor, accounting for 70 percent of the basin's sediment load (Figure LES6). Forested lands accounted for 18 percent of the sediment load. Mixed open land and urban sources contributed 8 and 4 percent, respectively.

Pocomoke River is a blackwater river and is designated as a Scenic River meaning that any development in the areas must be specifically approved by the Secretary of DNR.

Figure LES1 – Map of the Lower Eastern Shore Basin

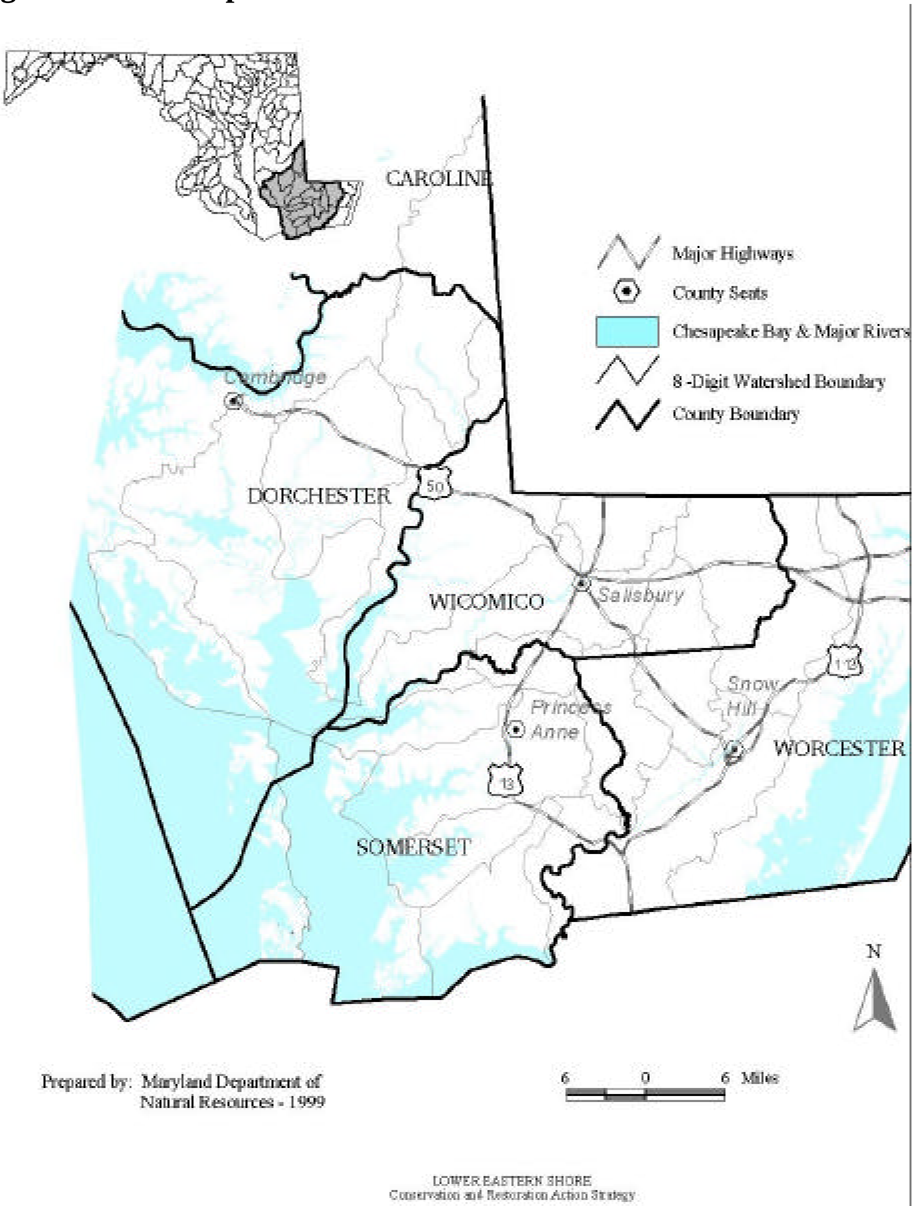


Figure LES2 – 2000 Land Use in the Lower Eastern Shore Basin.

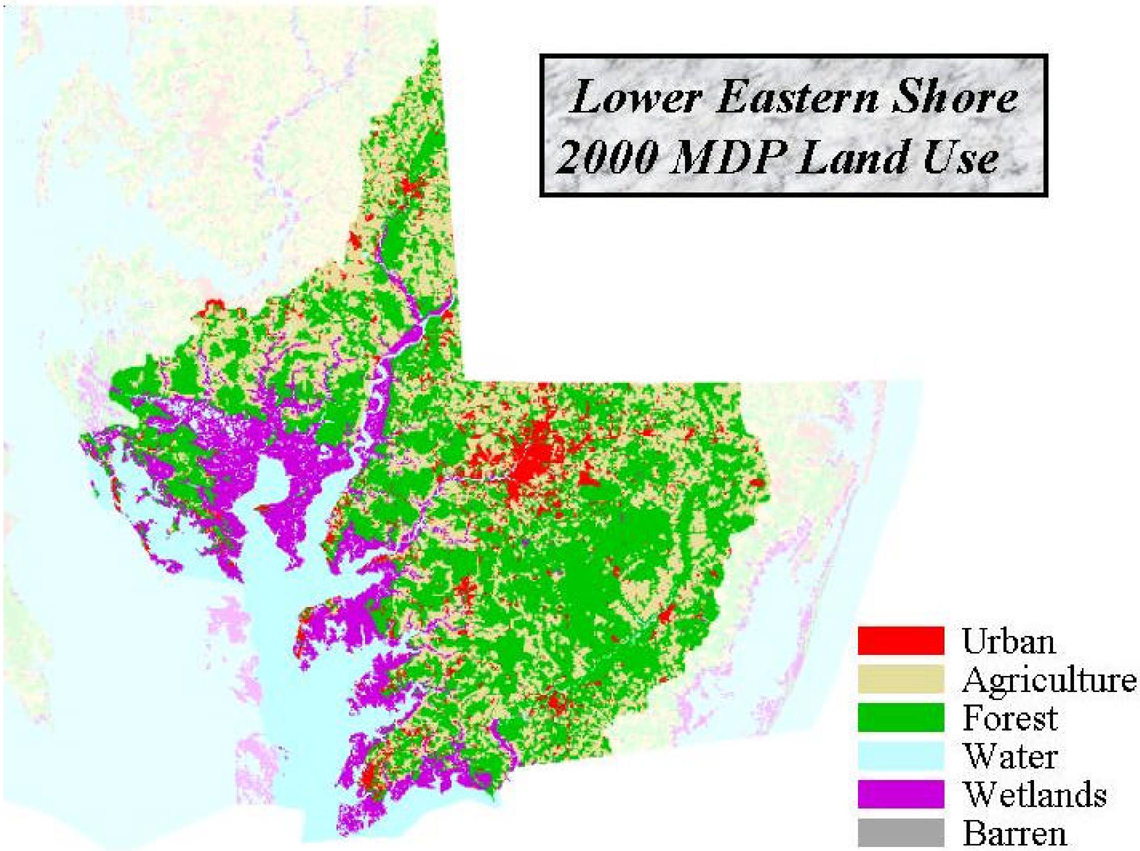


Figure LES3 – Wastewater Treatment Plants in the Lower Eastern Shore Basin.

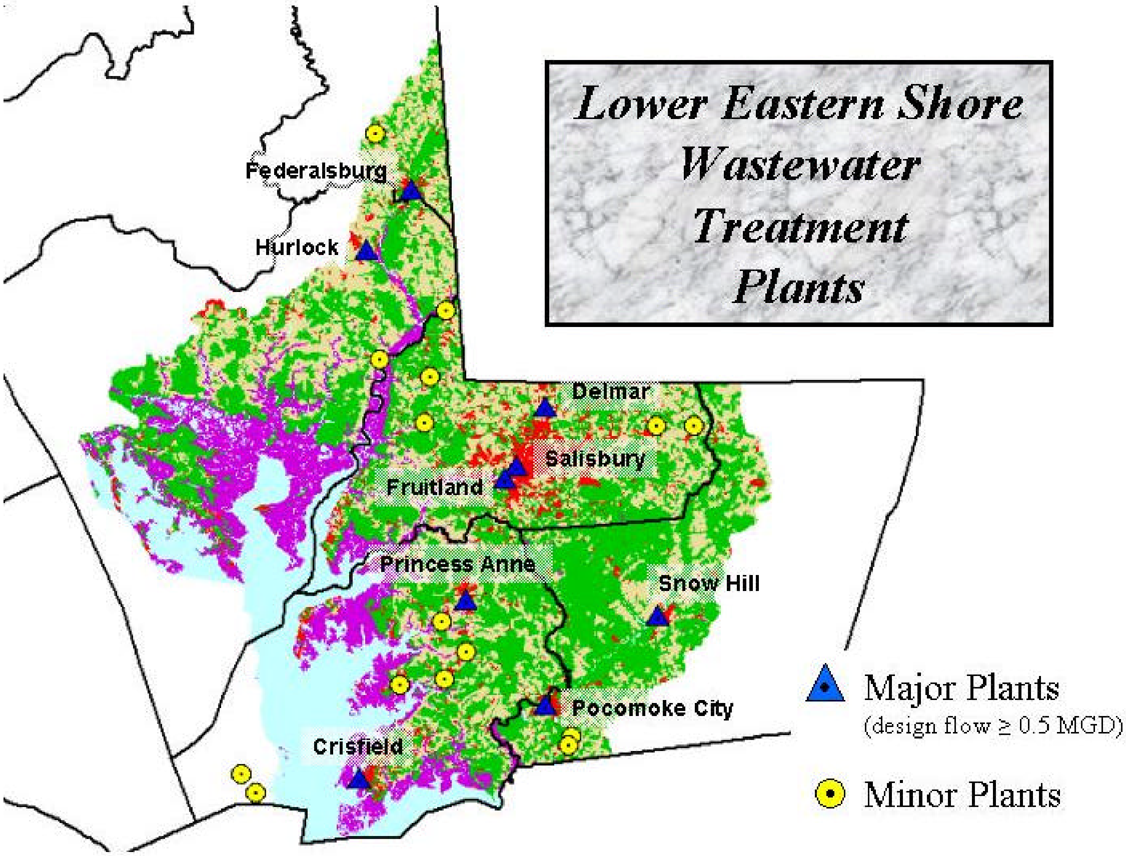


Figure LES4 – 1985 and 2002 Nitrogen Contributions to the Lower Eastern Shore by Source.

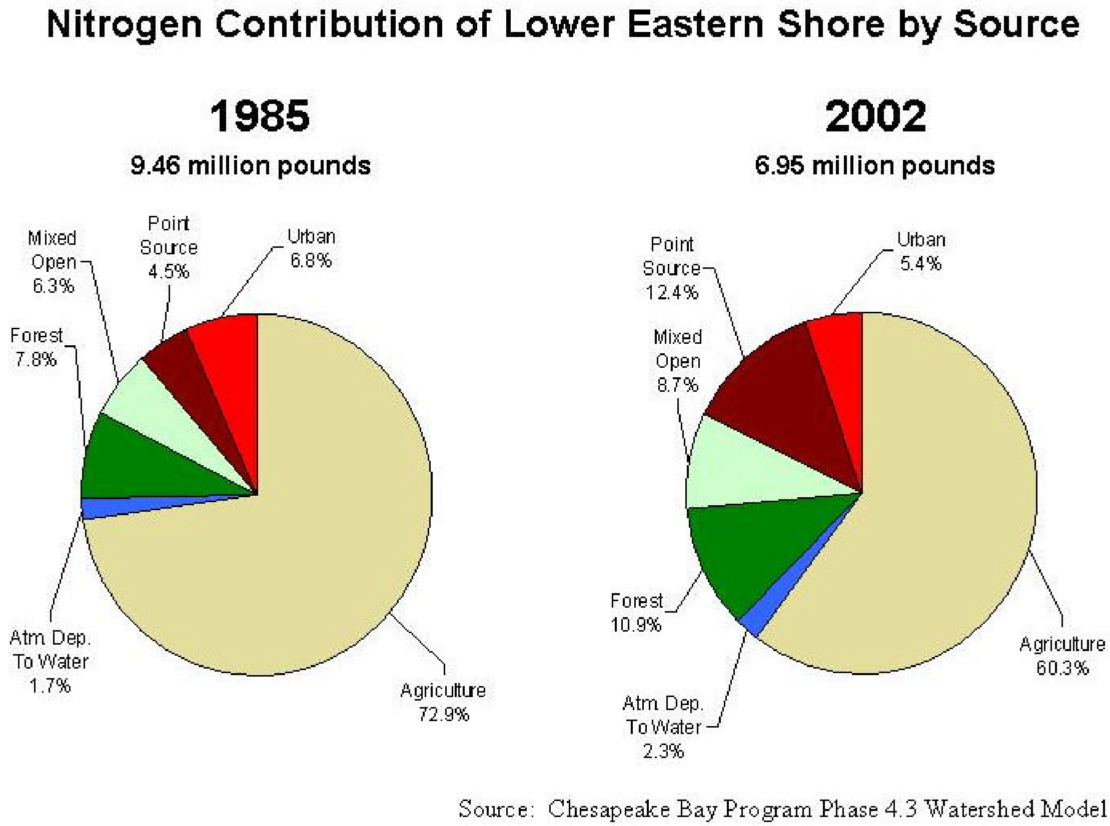
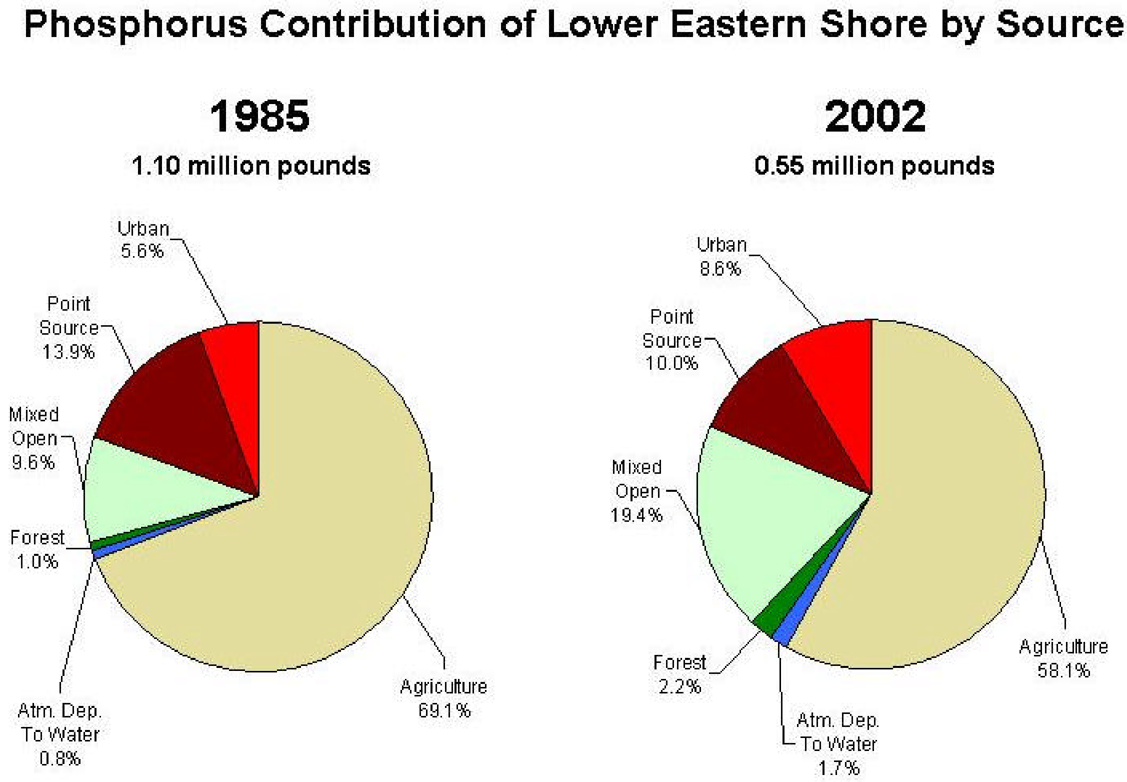
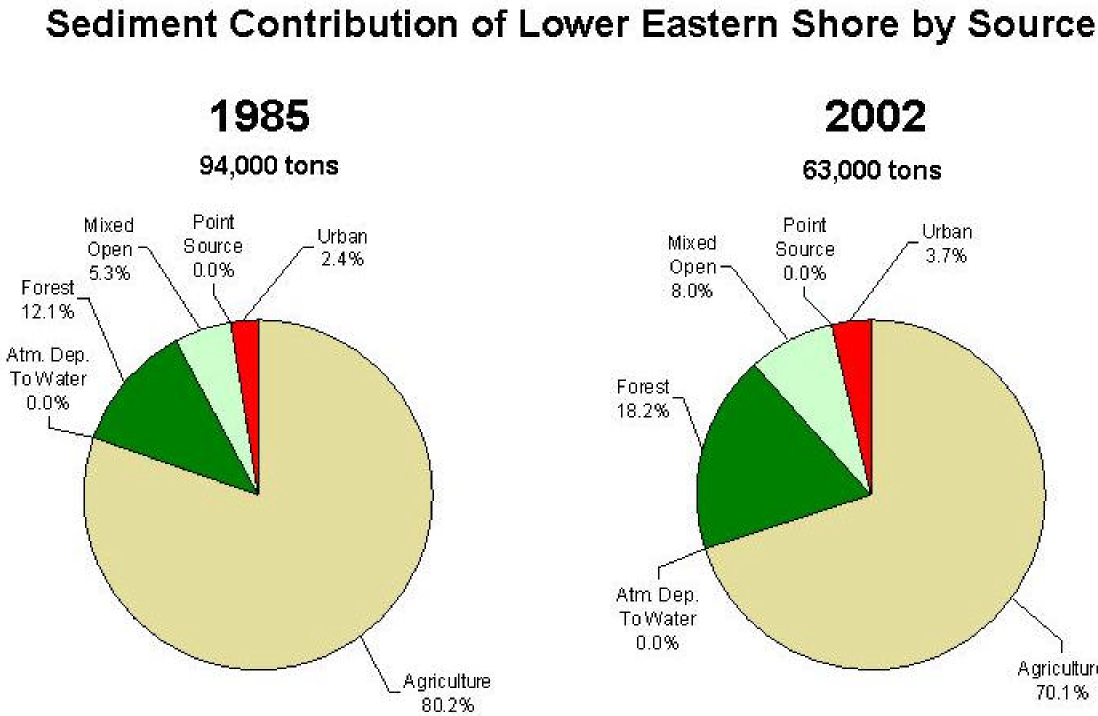


Figure LES5 – 1985 and 2002 Phosphorus Contributions to the Lower Eastern Shore by Source.



Source: Chesapeake Bay Program Phase 4.3 Watershed Model

Figure LES6 – 1985 and 2002 Sediment Contributions to the Lower Eastern Shore by Source.



Source: Chesapeake Bay Program Phase 4.3 Watershed Model

Figure LES7 – Total Nitrogen Status/Trends

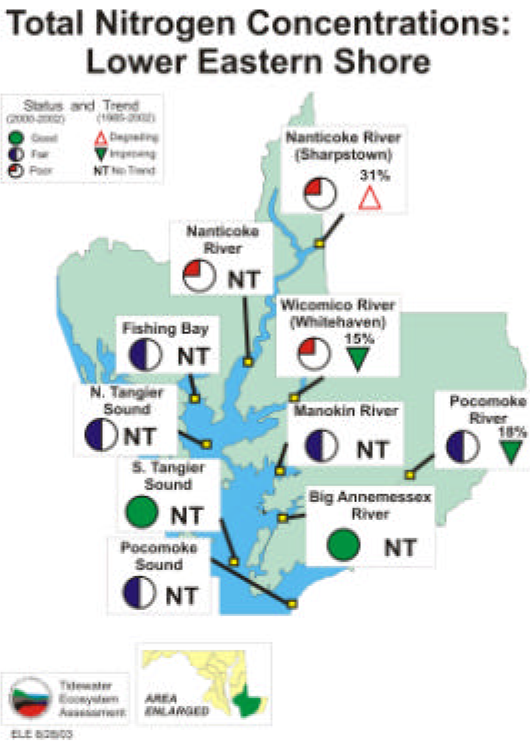


Figure LES8 – Total Phosphorus Status/Trends

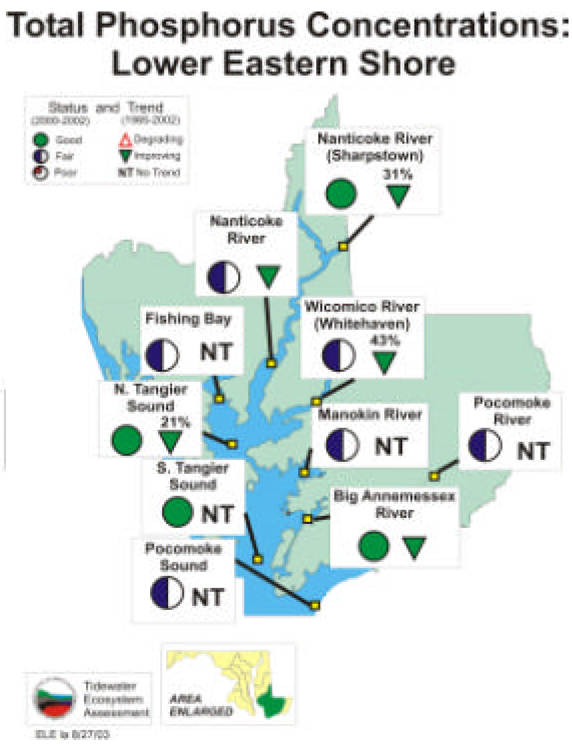


Figure LES9 – Chlorophyll Status and Trends

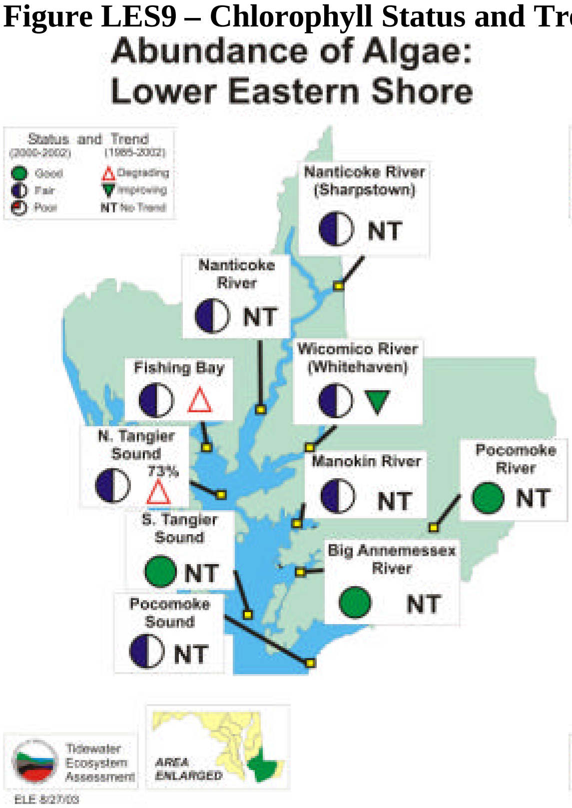


Figure LES10 – TSS Status/Trends

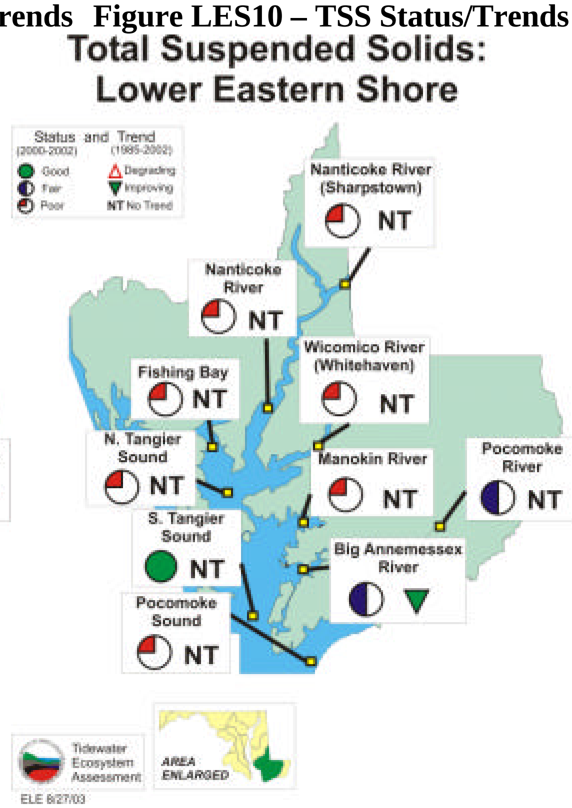


Figure LES11 – DO Status and Trends

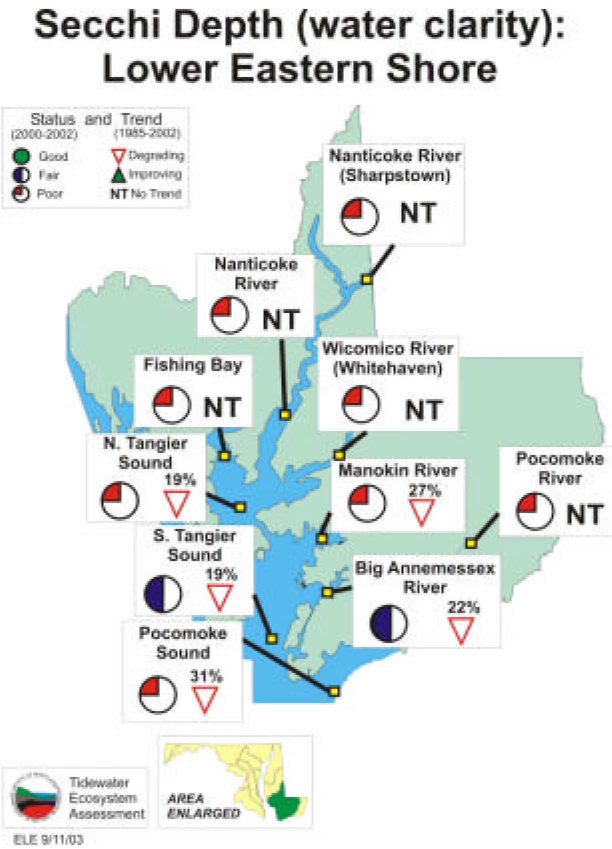
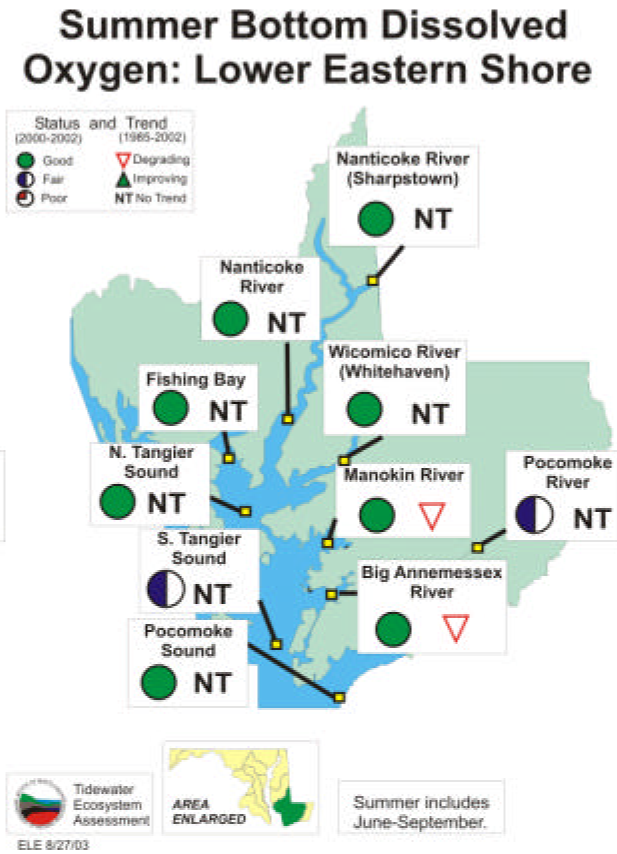


Figure LES12 – Secchi Depth Status and Trends



Overview of 2000 Monitoring Results

Water and Habitat Quality

Non-tidal Water Quality Monitoring Information Sources

Much useful information on non-tidal water quality is available on the Internet. The State of Maryland's Biological Stream Survey (MBSS) basin fact sheets and basin summaries are available at:
http://www.dnr.state.md.us/streams/mbss/mbss_fs_table.html
MBSS also reports stream quality information summarized by county at:
http://www.dnr.state.md.us/streams/mbss/county_pubs.html In addition to these reports and fact sheets, detailed and more recent information and data are also available on the MBSS website: **http://www.dnr.state.md.us/streams/mbss**

Water quality information collected by Maryland's volunteer Stream Waders is available at: **http://www.dnr.state.md.us/streams/mbss/mbss_volun.html**

Long-term Water Quality Monitoring

Good water quality is essential to support the animals and plants that live or feed in the Lower Eastern Shore tributaries. Important water quality parameters are measured at ten long-term tidal monitoring stations in the Lower Eastern Shore, including nutrients, water clarity (Secchi depth), dissolved oxygen, total suspended solids, and algal abundance.

Current status is determined based on the most recent three-year period (2000-2002). For dissolved oxygen, the current are compared to ecologically meaningful thresholds to assign a status of good, fair, or poor. Thresholds have not been established for the other parameters, so the current data are compared to a baseline data set, and assigned a status of good, fair, or poor, which is only a *relative* status compared to the baseline data. Trends are determined using a non-parametric test for trend (the Seasonal Kendall test). For a detailed description of the methods used to determine status and trends, see http://www.dnr.state.md.us/bay/tribstrat/status_trends_methods.html.

Many stations show no improvement in total nitrogen during the 1985 to 2002 period. In fact, total nitrogen levels have worsened (increased) at the Nanticoke Sharptown station. However, some stations show improvements in total phosphorus. Algal abundance has worsened (increased) in Tangier Sound. Many areas show high total suspended solids levels (poor status) and show poor and worsening water quality (Secchi depth). Clearly, more work is needed in order to improve nutrient and sediment levels. Nonetheless, most stations have good oxygen levels.

Intensive Monitoring

Intensive water quality monitoring in response to Harmful Algal Blooms (HABs) was conducted for five years (1998-2002). Now eight permanent long-term stations have been added to better characterize the systems. Continuous monitoring was done on the Chicamacomico at Drawbridge, and will be done on the Transquaking and Fishing Bay.

Water quality mapping has been conducted in Tangier Sound and will be done from Fishing Bay up Transquaking.

SAV

The well-defined linkage between water quality and submerged aquatic vegetation (SAV) distribution and abundance make SAV communities good barometers of the health of estuarine ecosystems. SAV is important not only as an indicator of water quality, but it is also a critical nursery habitat for many estuarine species. Blue crab post-larvae are 30 times more abundant in SAV beds than adjacent unvegetated areas. Similarly, several species of waterfowl are dependant on SAV as food when they over-winter in the Chesapeake region.

The Chesapeake Bay Program has developed new criteria for determining SAV habitat suitability of an area based on water quality. The APercent Light at Leaf@ habitat requirement assesses the amount of available light reaching the leaf surface of SAV after being attenuated in the water column and by epiphytic growth on the leaves themselves. The document describing this new model is found on the Chesapeake Bay Program website (www.chesapeakebay.net/pubs/sav/index.html). The older AHabitat Requirements@ of five water quality parameters are still used for diagnostic purposes. Re-establishment of SAV is measured against the ATier 1 Goal@, an effort to restore SAV to any areas known to contain SAV from 1971 to 1990.

Honga River had impressive gains in SAV coverage from 1984 until 1993, at which time the abundance exceeded the Tier I goal of 3951 by 15 percent (Figure LES13). Since 1993, SAV coverage declined precipitously to a low of 782 acres in 1998, and has been recovering since. The 2001 coverage was up significantly to 4947 acres (125 percent of the Tier I goal) the highest ever recorded. Ground-truthing by citizens, and staff from Chesapeake Bay Foundation, Salisbury State University and Virginia Institute of Marine Science (VIMS) has found widgeon grass and horned pondweed in this region. There is no water quality monitoring station in the Honga, so it is not possible to assess attainment of the SAV habitat requirements.

Fishing Bay also had impressive gains in SAV coverage from 1987 to 1994 (Figure LES13), with the results of the VIMS annual survey (www.vims.edu/bio/sav/) indicating that the Tier I goal of 33 acres was exceeded in 1992, 1993 and 1994 (by over 94 percent in 1994). However, SAV abundance declined in 1995 and was absent in 1996 through 1998. 5 acres of SAV was identified in 1999 and 6 acres in both 2000 and 2001. There is no ground-truthing information from Fishing Bay. Water quality data from the monitoring station located near Roasting Ear Point indicates that only phosphorous, algae and nitrogen concentrations meet the SAV habitat requirements, with suspended solid levels borderline. Percent light at leaf and light attenuation fail the SAV habitat requirements.

In the Nanticoke River, SAV has never been mapped by the VIMS aerial survey (Figure LES13) and there is not a Tier I goal in this area (www.vims.edu/bio/sav/). In 1996, a citizen ground-truthing the upper part of the river did find wild celery, coontail, hydrilla, slender pondweed, an unidentified naiad, and other unidentified species of SAV in Gales

Creek, near the Maryland/Delaware state line. Also, staff from EPA did find horned pondweed in Shiles Creek in 1996. A wild celery *(Vallisneria americana)* transplant was tested on Marshyhope Creek in 2001 and 2002, a tributary of the Nanticoke, near the town of Federalsburg. This transplant failed, due to grazing and borderline conditions. Water quality data from the monitoring station located near the bridge at Sharpstown (tidal fresh region) indicates that most of the SAV habitat requirements fail in this area (percent light at leaf, light attenuation, and concentration of suspend solids), with only phosphorous concentration passing and algae levels borderline. Nitrogen levels are not applicable as SAV habitat requirements in this tidal fresh region. In the lower Nanticoke River (mesohaline) the water quality monitoring data from the station located near Wetipquin Neck indicates that phosphorous concentrations pass and algae and nitrogen are borderline in respect to the SAV habitat requirements, while percent light at leaf, light attenuation and concentration of suspended solids fail these requirements.

In the Wicomico River, SAV has never been mapped by the VIMS aerial survey (Figure LES13) and there is not a Tier I goal in this area (www.vims.edu/bio/sav/). Ground-truthing by staff from EPA did find horned pondweed in Wetipquin Creek. Data from the water quality monitoring station located at Whitehaven indicate that phosphorous and algae levels passed the SAV habitat requirements, nitrogen concentrations were borderline. Suspended solids levels, percent light at leaf and light attenuation failed the SAV habitat requirements.

The Manokin River has had highly variable SAV coverage (Figure LES13) as mapped by the VIMS aerial survey (www.vims.edu/bio/sav/), particularly in recent years (since 1994). In this time frame, SAV abundance has ranged from a low of 20 acres to a high of 451 acres in 2000, or 66 percent of the Tier I goal of 683 acres. 2001 had 404 acres of SAV. These SAV beds have all been mapped downstream of Locus Point. Ground-truthing by citizens and staff from VIMS between 1994 and 1998 has identified only widgeon grass in this area. Water quality data from the monitoring station located near Inverness indicate that levels of nitrogen, phosphorous and algae meet the SAV habitat requirement, suspended solids is borderline, and percent light at leaf and light attenuation fail.

The Big Annemessex River has had fairly consistent SAV coverage of approximately 400 acres for the last 15 years (Figure LES13), with some fluctuations as mapped by the VIMS aerial survey (www.vims.edu/bio/sav/). In 2001, SAV coverage was 721 acres, the largest ever recorded by VIMS, representing approximately 80 percent of the Tier I goal of 901 acres. No ground-truthing has occurred in this river. Water quality data obtained at a station located between Long and Scott Points indicate that most SAV habitat requirements are met (percent light at leaf and concentrations of nitrogen, phosphorous and algae). Light attenuation and suspended solid concentrations are borderline.

In the Pocomoke River, upstream of Williams Point, Virginia Institute of Marine Science has never mapped SAV in the annual aerial survey (www.vims.edu/bio/sav/), and there is no Tier I goal (Figure LES13). In addition, there are no ground-truthing sites in this area. Data from the water quality monitoring station located at the drawbridge in Pocomoke City indicates that only algae levels passed the SAV habitat requirements and suspended solids are borderline, while percent light at leaf, light attenuation, and phosphorous concentrations failed. Nitrogen levels are not applicable in this oligohaline environment.

Pocomoke Sound has had fairly consistent SAV coverage as delineated by the VIMS aerial survey (www.vims.edu/bio/sav/), with abundance peaking in 1993 at 1,916 acres or 92 percent of the Tier I goal (2,078 acres) (Figure LES13). Since then, however, SAV coverage fell to 59 acres in 2001. Most of the SAV beds are located between Oystershell Point and the Cedar Straights. Ground-truthing by VIMS staff in the area has found widgeon grass and eelgrass. Data from the water quality monitoring station located in the middle of Pocomoke Sound, near state line marker AA@, indicates that concentrations of algae, nitrogen and phosphorous pass, percent light at leaf and suspended solids concentration are borderline and light attenuation fails relative to the SAV Habitat Requirement.

Tangier Sound had a good resurgence of SAV, hitting a high of 18,113 acres in 1992, near the Tier I goal of 19,899 acres (Figure LES13). Since then, SAV suffered massive declines to a low of 6,612 acres in 1998 (33 percent of the Tier I goal). 2001 witnessed a rebound to 13,328 acres (www.vims.edu/bio/sav/). Ground-truthing by a citizen and VIMS staff has found widgeon grass and eelgrass throughout Tangier Sound. There are two water quality monitoring stations in Tangier Sound (one near Sharkfin Shoal, the other off of Island Point, near Janes Island), and these data indicate that algae, nitrogen, phosphorous and suspended solids concentrations meet the SAV habitat requirements, while light attenuation and percent light at leaf is borderline

Figure LES13 – SAV Distribution in the Lower Eastern Shore Basin

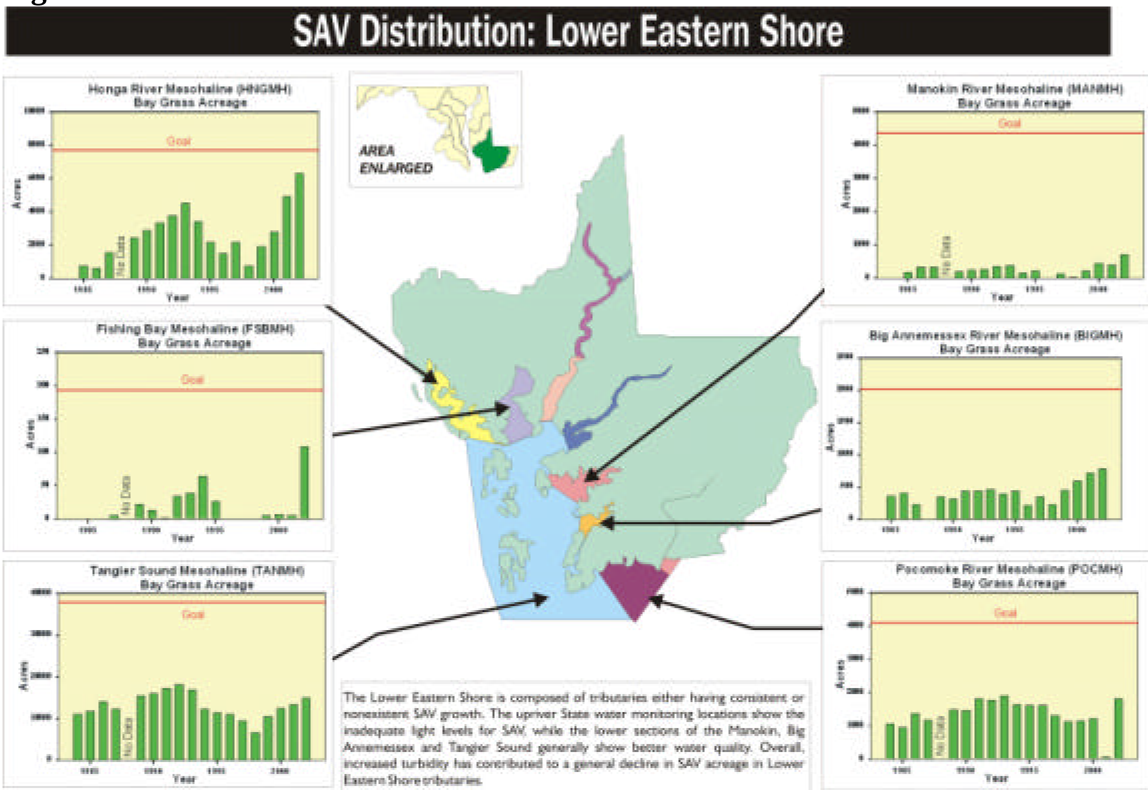


Figure 1a: SAV coverage on the Lower Eastern Shore, 1984 to 2002

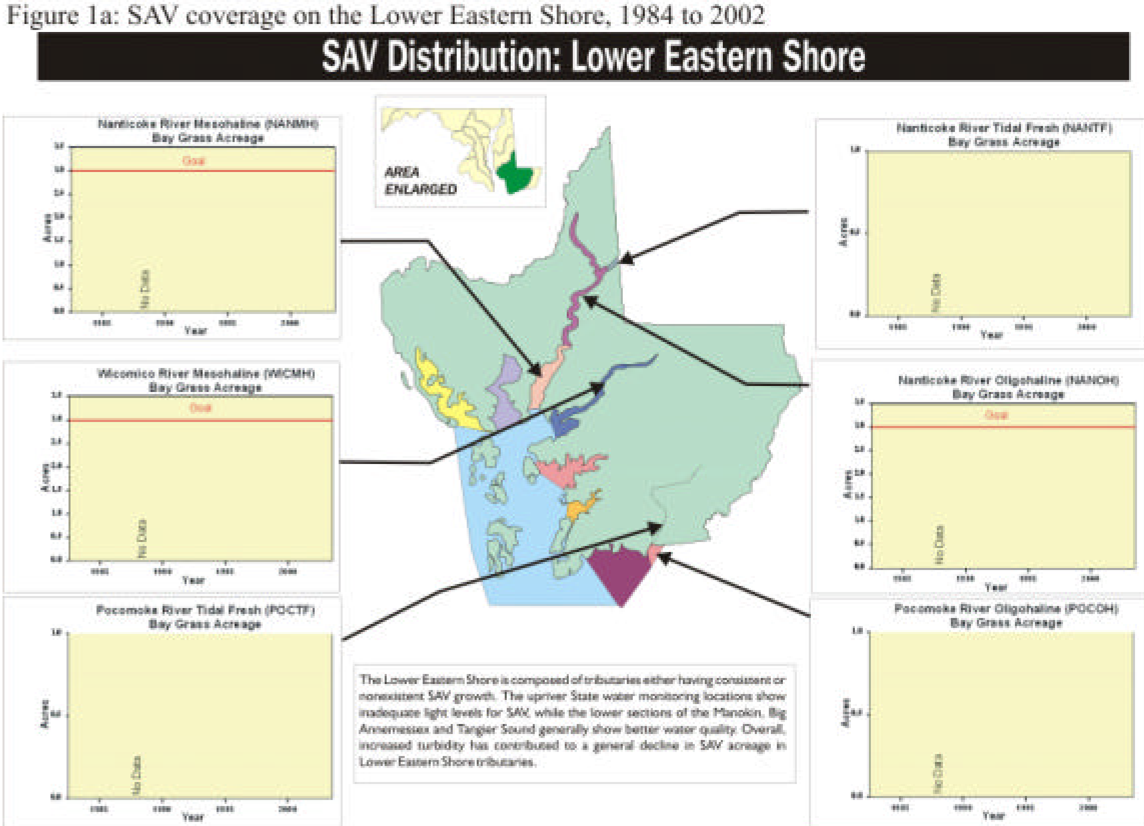


Figure 1b: SAV coverage on the Lower Eastern Shore, 1984 to 2002

Benthic Community

The benthic community forms an integral part of the ecosystem in estuarine systems. For example, small worms and crustaceans are key food items for crabs and demersal fish, such as spot and croaker. Suspension feeders that live in the sediments, such as clams, can be extremely important in removing excess algae from the water column. Benthic macroinvertebrates are reliable and sensitive indicators of estuarine habitat quality.

Benthic monitoring includes both probability-based sampling (sampling sites are selected at random) and fixed station sampling (the same site is sampled every year). A benthic index of biotic integrity (B-IBI) is determined for each site (based on abundance, species diversity, etc.). The B-IBI serves as a single-number indicator of benthic community health. For a more details on the methods used in the benthic monitoring program see http://esm.versar.com/Vcb/Benthos/backgrou.htm

During the period 1994-2000, lower eastern shore basin tributaries exhibited good overall benthic community condition. Condition was best in the Nanticoke and Wicomico River estuaries, where the probabilities of observing non-degraded benthos were relatively high with good confidence. Good benthos and probabilities greater than 50 percent were observed in the Nanticoke, Wicomico, and Manokin River estuaries, as well as in Tangier Sound (Table LE1). Tangier Sound and the Big Annemessex River had the highest number of samples failing the B-IBI; however, about 45 percent of the failing sites were only marginally degraded. This is reflected in the relatively high probabilities of observing benthos of intermediate quality in these two systems, especially in the Big Annemessex River (Table LE1). Pocomoke Sound also had a relatively high probability of benthos of intermediate quality.

Sites with failing B-IBI values generally exhibited low abundance and/or biomass. Low biomass, however, was a problem affecting all lower eastern shore basin tributaries. For example, all three failing sites in the mesohaline portion of the Nanticoke River failed the B-IBI because of low biomass. A fixed long-term monitoring station in the Nanticoke River exhibited a degrading trend for the B-IBI (Table LE2) and degrading trends in biomass and species diversity. Low biomass was particularly a problem in Fishing Bay (57 percent of all samples), the Manokin River (75 percent), and Tangier Sound (69 percent). The major problem affecting water quality in lower eastern shore basin tributaries is high sediment loads. A link between high sediment loads and low benthic community biomass can be hypothesized, either through impacts on benthic fauna from siltation or reductions in planktonic food for filter-feeding organisms.

It is also of note that before the infestation of MSX, many areas in the Lower Eastern Shore were prime oyster production area.

Nutrient Limitation

Like all plants, phytoplankton need nitrogen, phosphorus, light, and suitable water temperatures to grow. If light is adequate and the water temperature is appropriate, phytoplankton will continue to grow as long as unlimited amounts of nutrients are available. If nutrients are not unlimited, then the ratio of nitrogen to phosphorus affects phytoplankton growth. (Phytoplankton generally use nitrogen and phosphorus at a ratio of 16:1, that is, 16 times as much nitrogen is needed as phosphorus.) If one of the nutrients is not available in the adequate quantity, phytoplankton growth is 'limited' by that nutrient. If both nutrients are available in enough excess (regardless of the relative proportion of them) that the phytoplankton can not use them all even when they are growing as fast as they can under the existing temperature and light conditions, then the system is 'nutrient saturated.'

Nitrogen limitation occurs when there is insufficient nitrogen, i.e., there is excess phosphorus. Nitrogen limitation often happens in the summer and fall after stormwater flows are lower (so less nitrogen is being added to the water) and some of the nitrogen has already been used up by phytoplankton growth during the spring. If an area is nitrogen limited, then adding nitrogen will increase phytoplankton growth.

Phosphorus limitation occurs when there is insufficient phosphorus, i.e. there is excess nitrogen. If an area is phosphorus limited, then adding phosphorus will increase phytoplankton growth. Phosphorus limitation occurs in some locations in the spring when large amounts of nitrogen are added to the estuary from stormwater flow.

If an area is light limited, then both nitrogen and phosphorus are available in excess and a situation of nutrient saturation occurs. In this case, if phytoplankton are exposed to appropriate water temperatures and sufficient light, they will grow. If an area is both nitrogen and phosphorus limited, then both nitrogen and phosphorus must be added to increase algal growth.

Managers can use the nutrient limitation model to predict which nutrient is limiting at a given location and use the information to assess what management approach might be the most effective for controlling excess phytoplankton growth. If an area is phosphorus limited, then reducing phosphorus will bring the most immediate reductions in phytoplankton grown. However, if nitrogen levels are not also reduced, the excess nitrogen that goes unused can be exported downstream. This excess nitrogen may reach an area that is nitrogen limited, fueling phytoplankton growth in that downstream area.

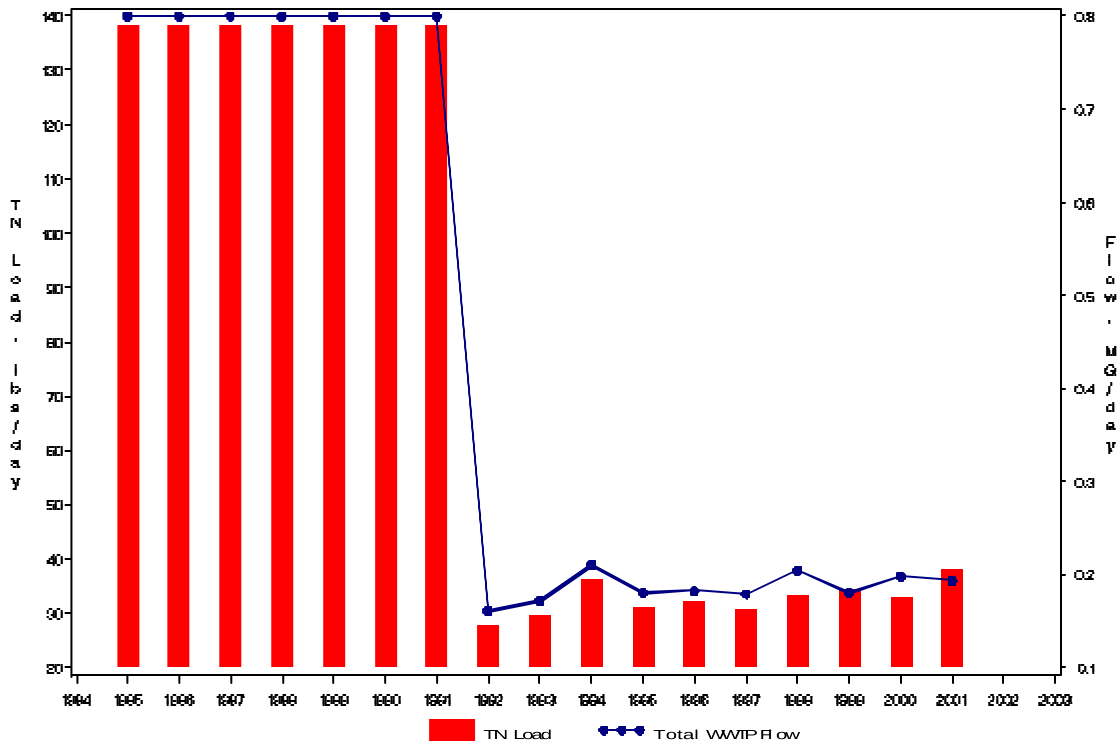
The nutrient limitation predictions are a valuable tool, but they must be used in conjunction with other water quality and watershed information to fully assess and evaluate the best management approach.

The nutrient limitation models were used to predict nutrient limitation for the ten stations in the Lower Eastern Shore. Results are summarized for the most recent three-year period (2000-2002) by season: winter (December-February), spring (March-May), summer (July-September) and fall (October-November).

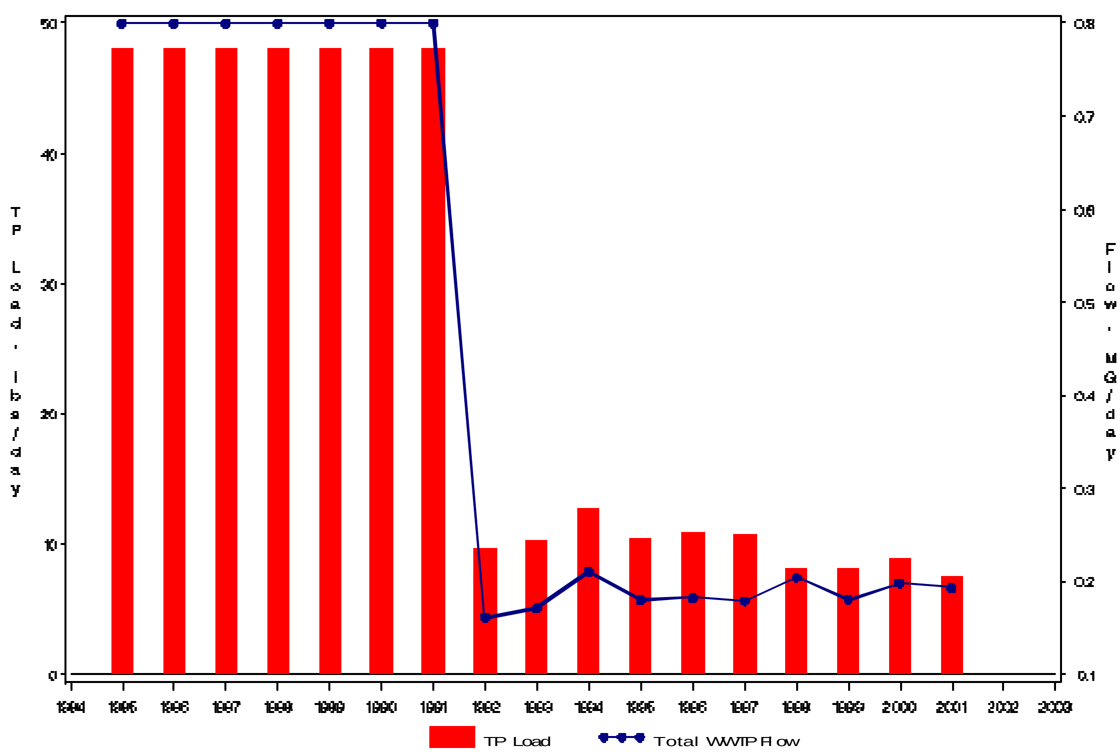
Managers can use these predictions to assess what management approach will be the most effective for controlling excess phytoplankton growth. Interpreting the results can be a little counter-intuitive, however. Remember that nitrogen limited means that *phosphorus* is in excess. Initially, it would seem that the best management strategy would be to reduce phosphorus inputs. However, it may actually be more cost effective to further reduce *nitrogen* inputs to increase the amount of 'unbalance' in the relative proportions of nutrients so that phytoplankton growth is even more limited. When used along with other information available from the water quality and watershed management programs, these predictions will allow managers to make more cost-effective management decisions.

Appendix A – Nutrient Loads from Major WWTPs in the Lower Eastern Shore

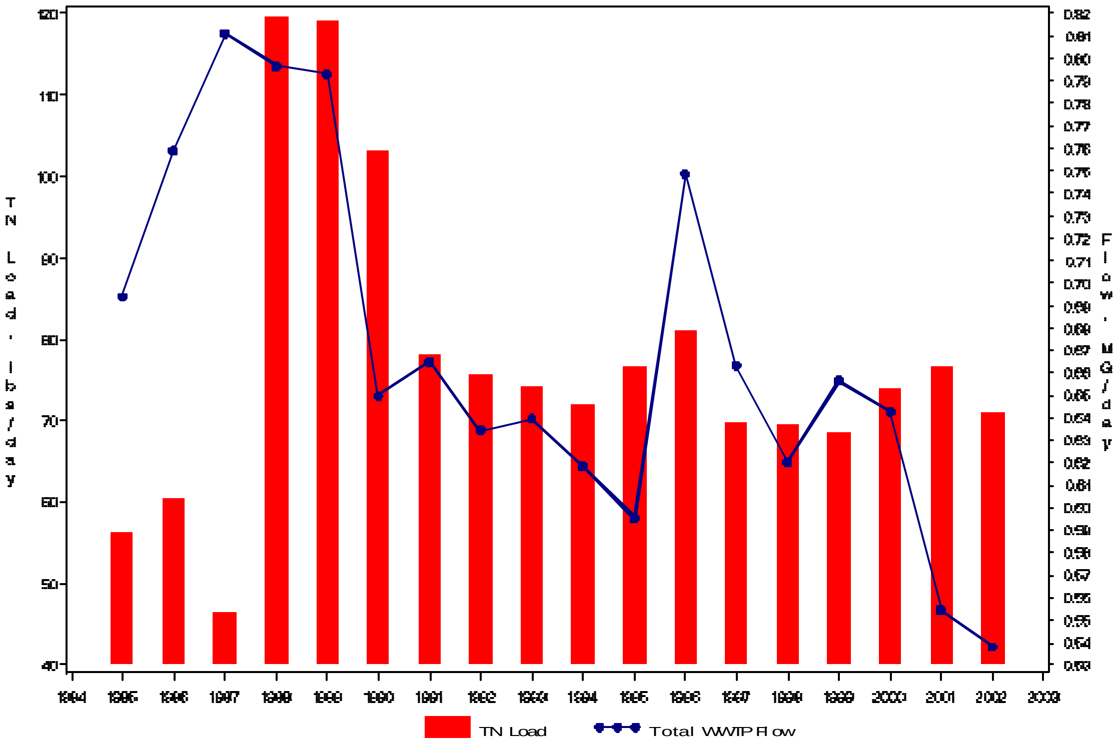
BRIDGEVILLE Wastewater Treatment Plant: Lower Eastern Shore Tributary Strategy Basin
Mean Daily Total Nitrogen Loads and Flow



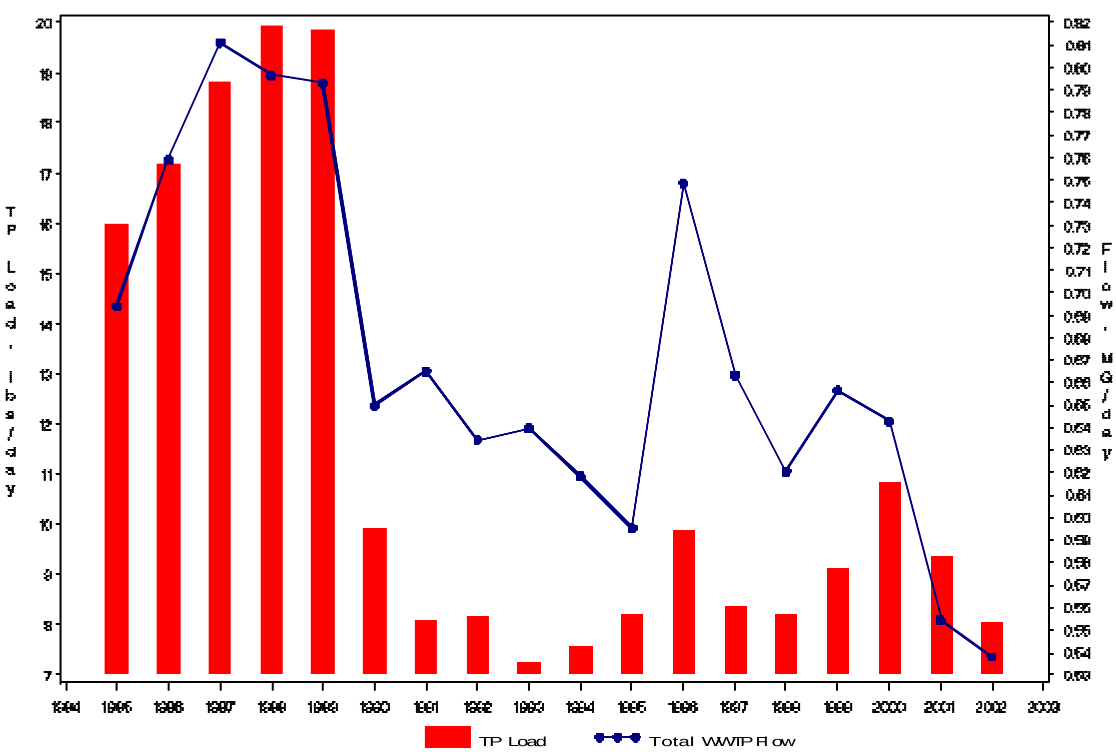
BRIDGEVILLE Wastewater Treatment Plant: Lower Eastern Shore Tributary Strategy Basin
Mean Daily Total Phosphorus Loads and Flow



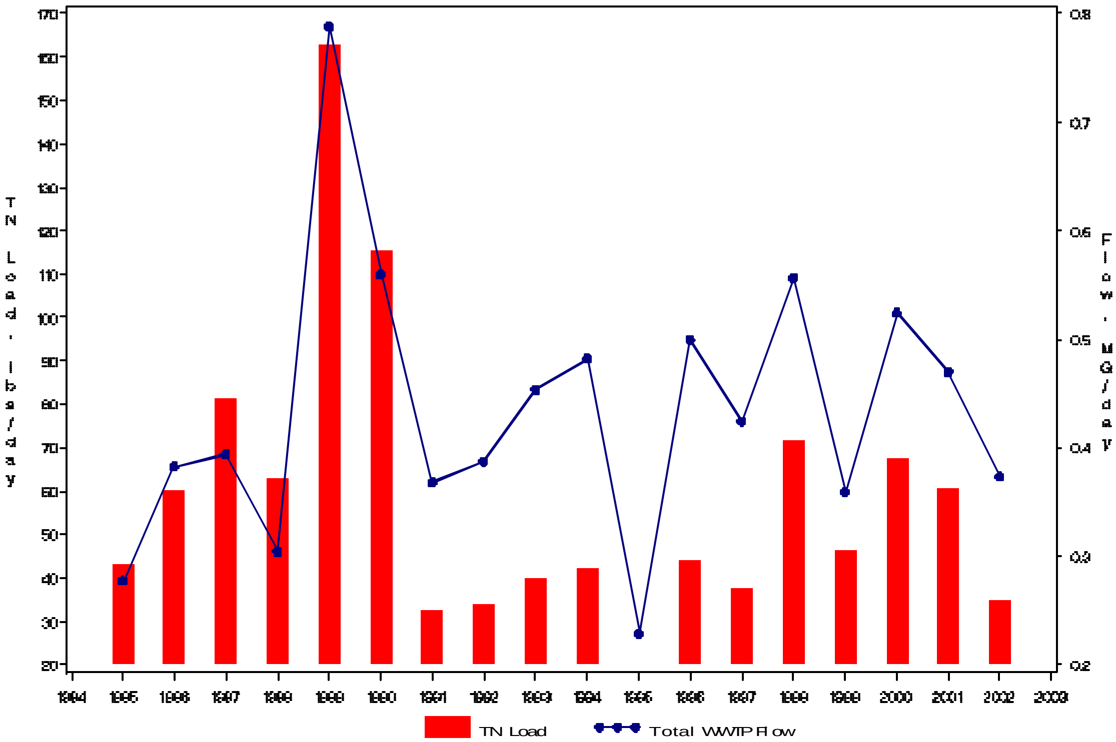
CRISFIELD Wastewater Treatment Plant: Lower Eastern Shore Tributary Strategy Basin
Mean Daily Total Nitrogen Loads and Flow



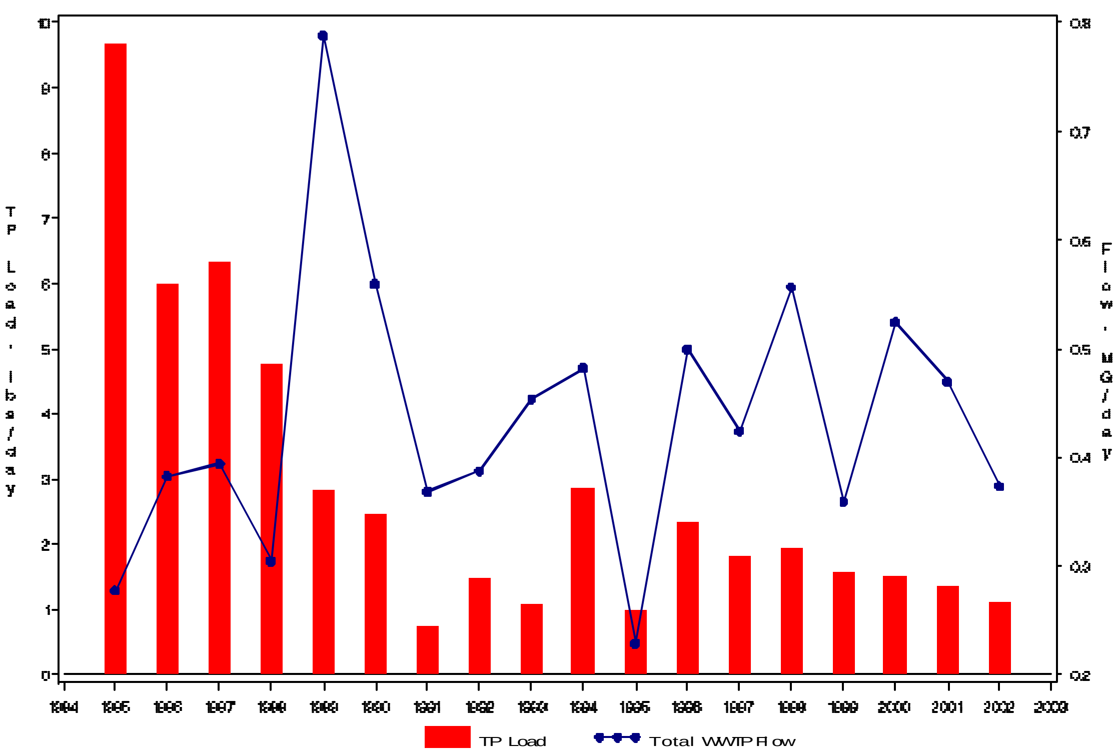
CRISFIELD Wastewater Treatment Plant: Lower Eastern Shore Tributary Strategy Basin
Mean Daily Total Phosphorus Loads and Flow



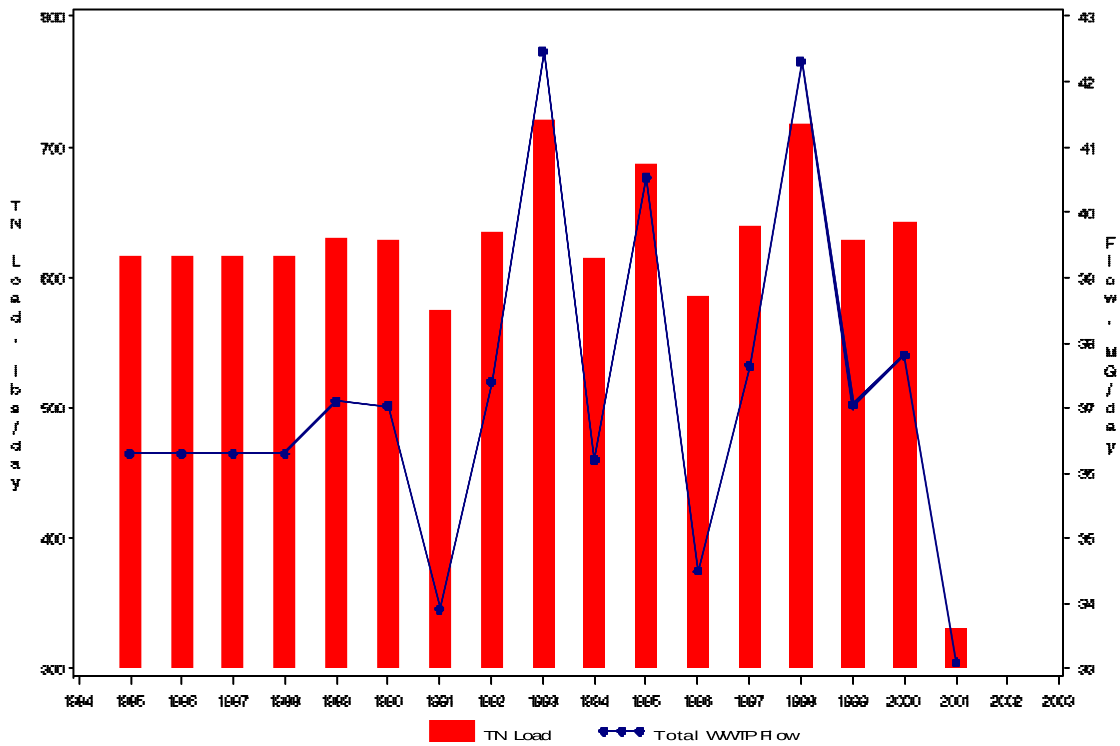
DELMAR Wastewater Treatment Plant: Lower Eastern Shore Tributary Strategy Basin
Mean Daily Total Nitrogen Loads and Flow



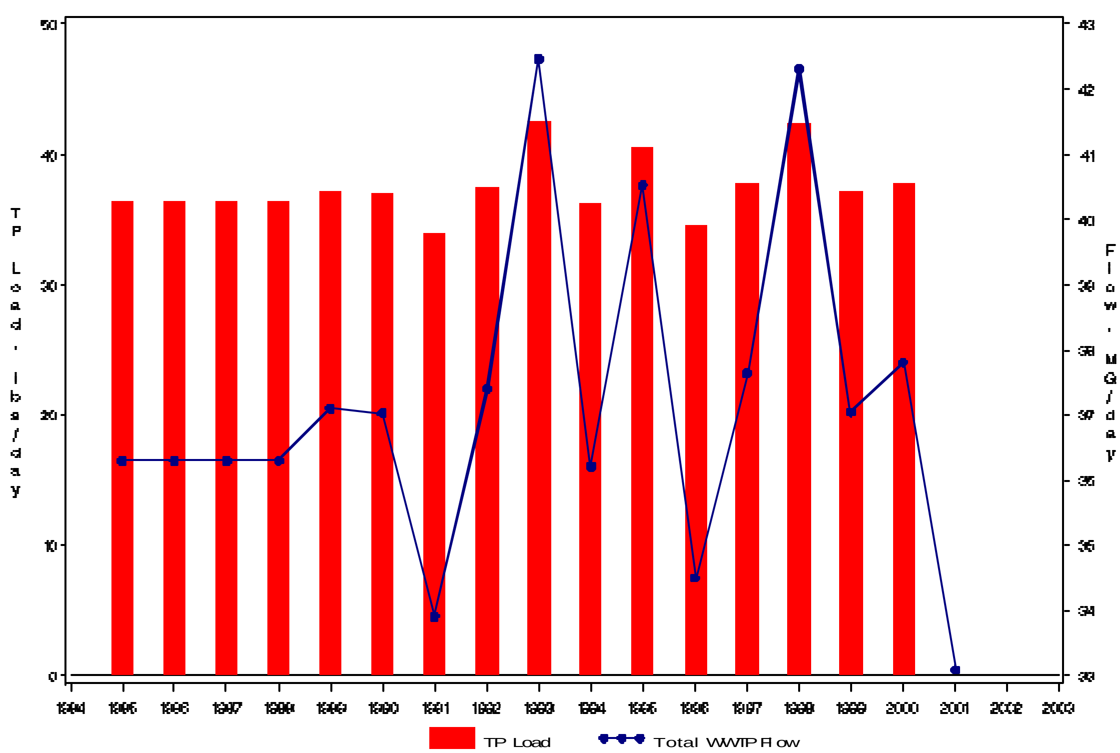
DELMAR Wastewater Treatment Plant: Lower Eastern Shore Tributary Strategy Basin
Mean Daily Total Phosphorus Loads and Flow



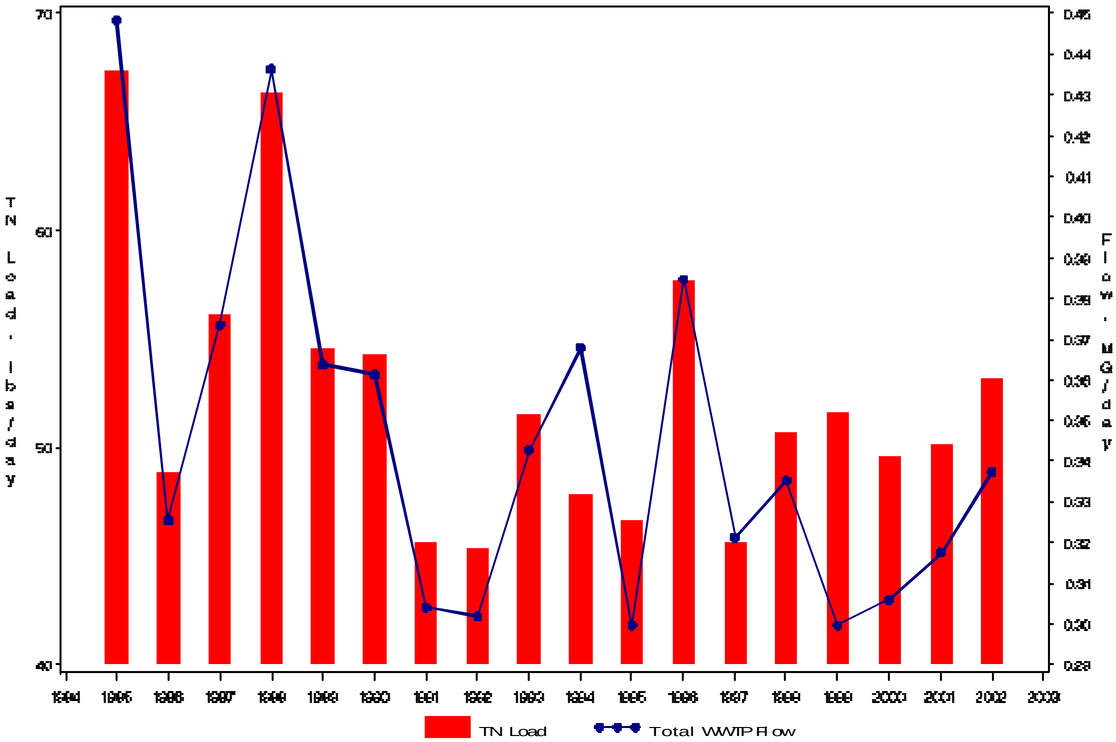
DUPONT—SEAFORD Wastewater Treatment Plant: Lower Eastern Shore Tributary Strategy Basin
Mean Daily Total Nitrogen Loads and Flow



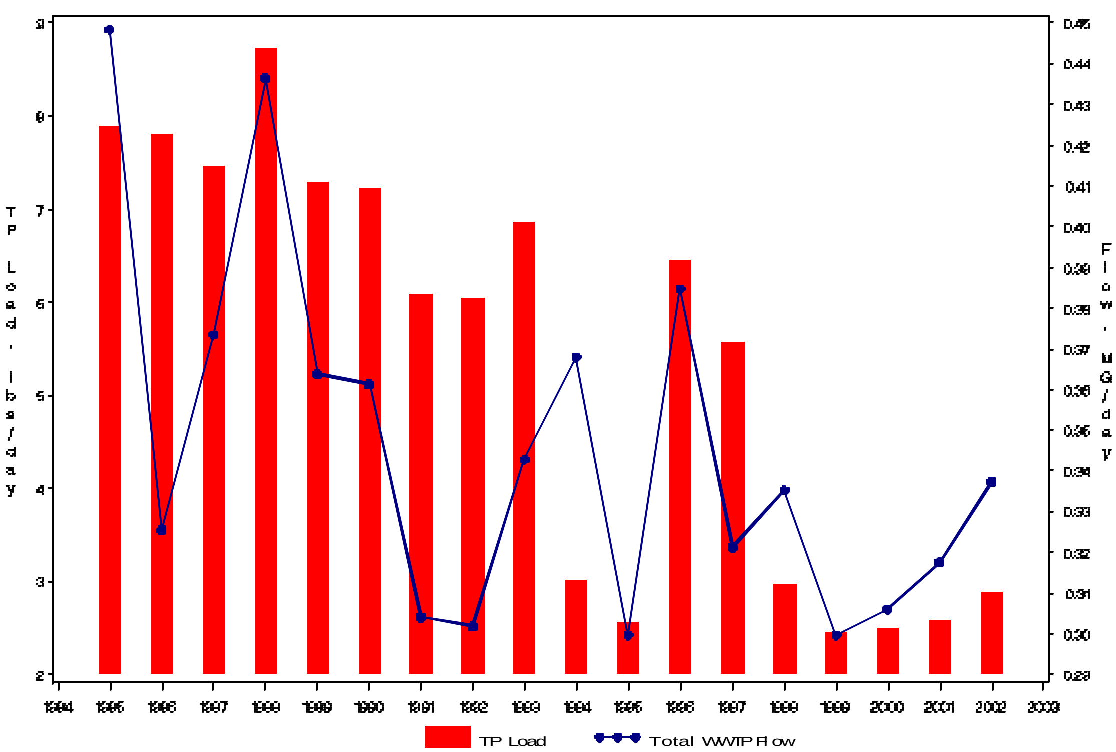
DUPONT—SEAFORD Wastewater Treatment Plant: Lower Eastern Shore Tributary Strategy Basin
Mean Daily Total Phosphorus Loads and Flow



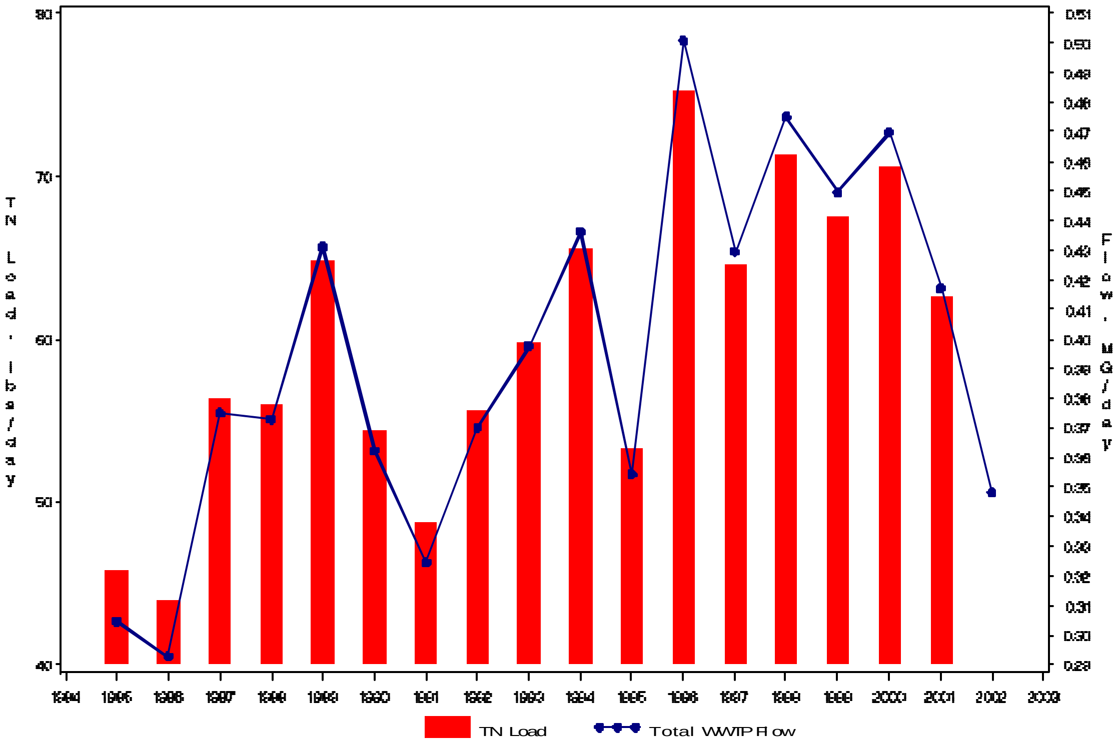
FEDERALSBURG Wastewater Treatment Plant: Lower Eastern Shore Tributary Strategy Basin
Mean Daily Total Nitrogen Loads and Flow



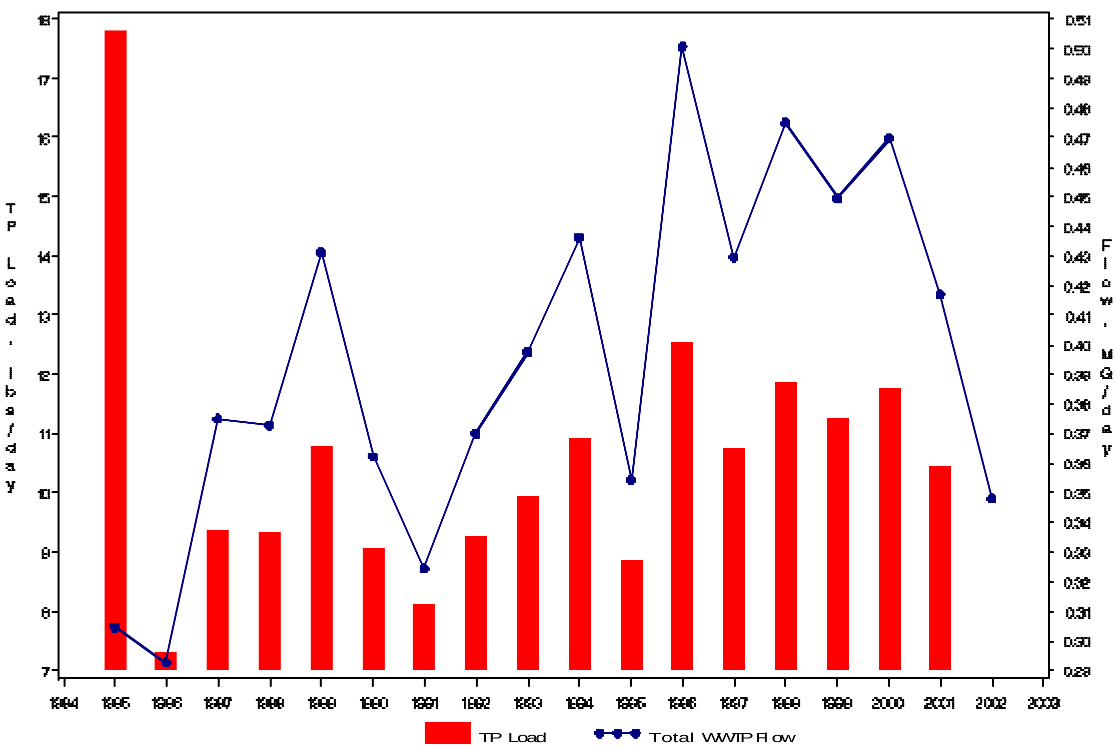
FEDERALSBURG Wastewater Treatment Plant: Lower Eastern Shore Tributary Strategy Basin
Mean Daily Total Phosphorus Loads and Flow



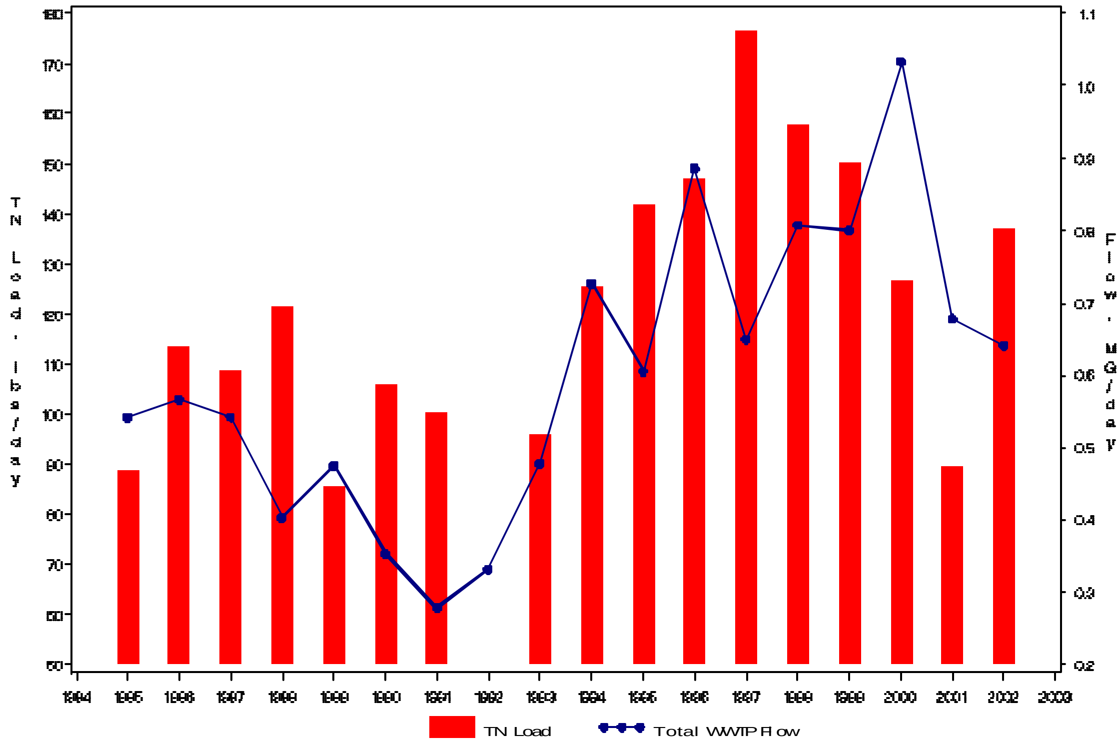
FRUITLAND Wastewater Treatment Plant: Lower Eastern Shore Tributary Strategy Basin
Mean Daily Total Nitrogen Loads and Flow



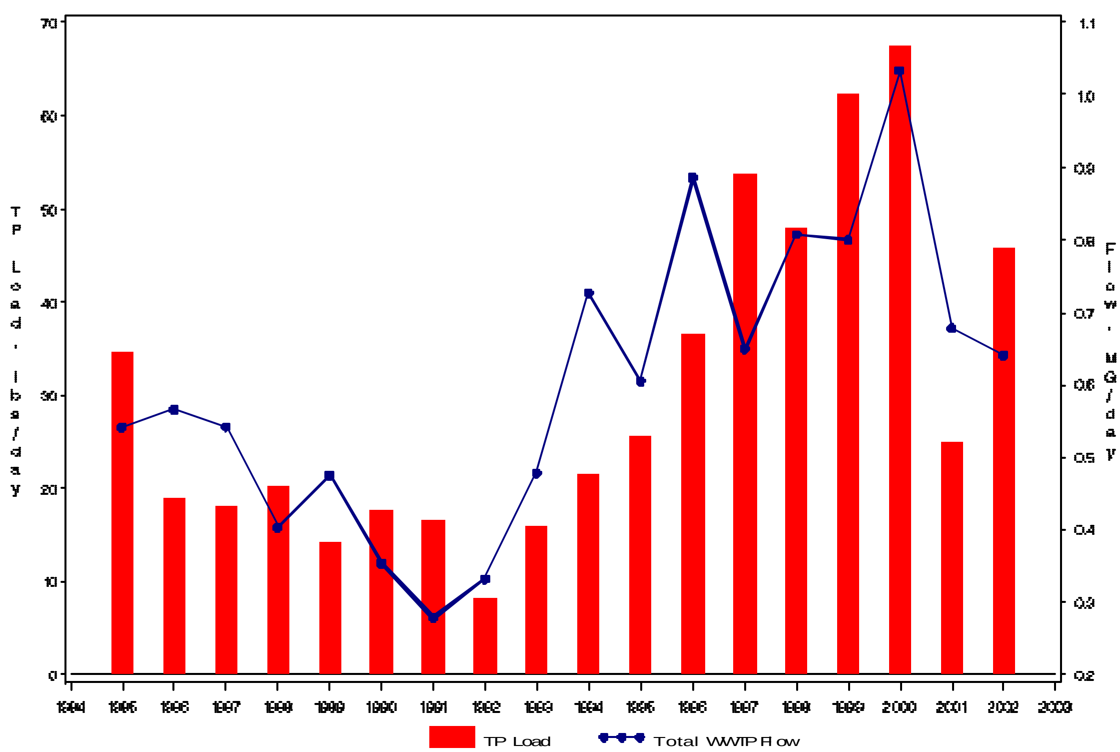
FRUITLAND Wastewater Treatment Plant: Lower Eastern Shore Tributary Strategy Basin
Mean Daily Total Phosphorus Loads and Flow



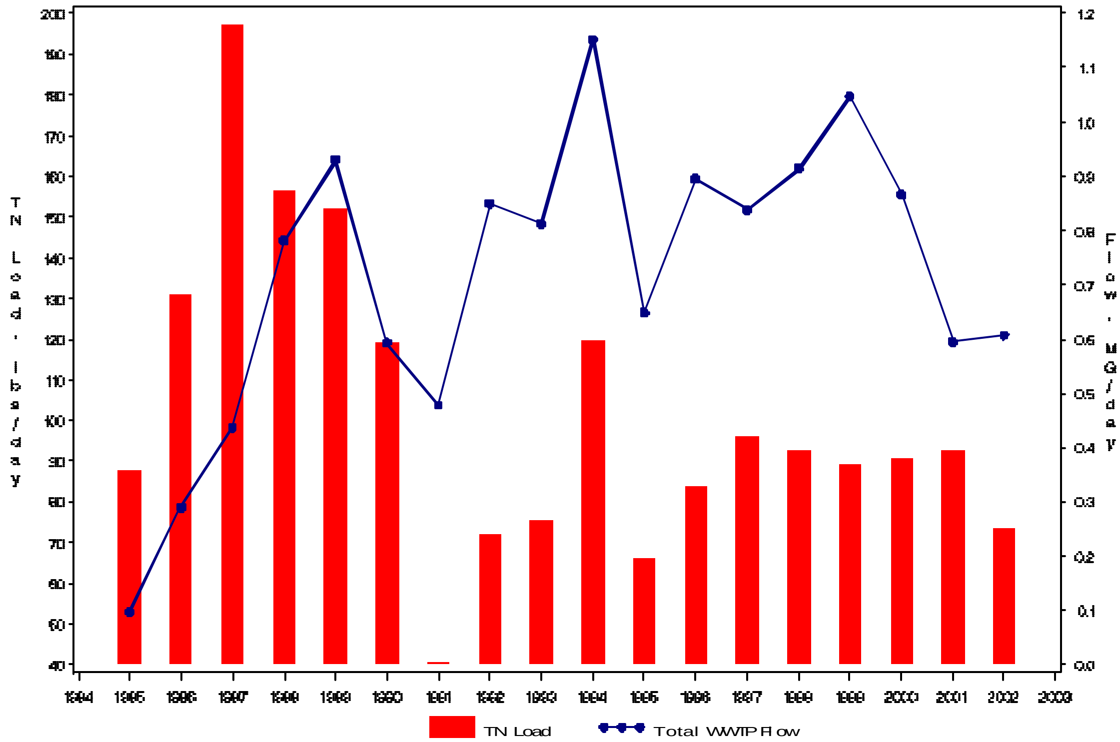
HURLOCK Wastewater Treatment Plant: Lower Eastern Shore Tributary Strategy Basin
Mean Daily Total Nitrogen Loads and Flow



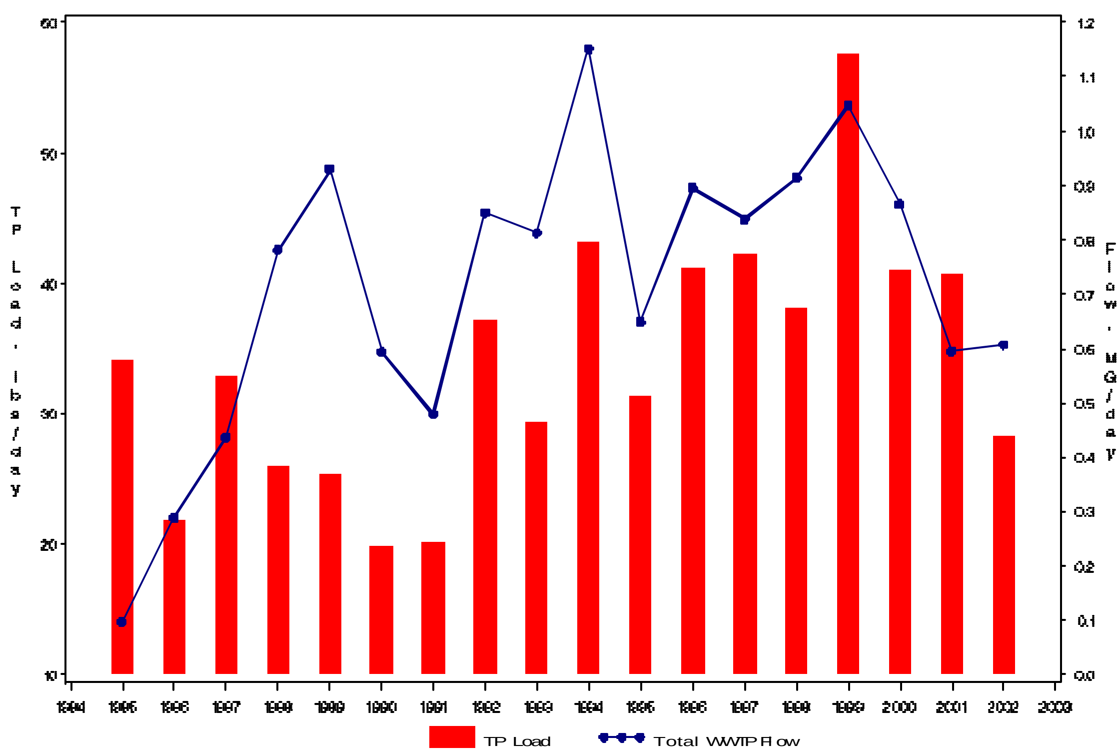
HURLOCK Wastewater Treatment Plant: Lower Eastern Shore Tributary Strategy Basin
Mean Daily Total Phosphorus Loads and Flow



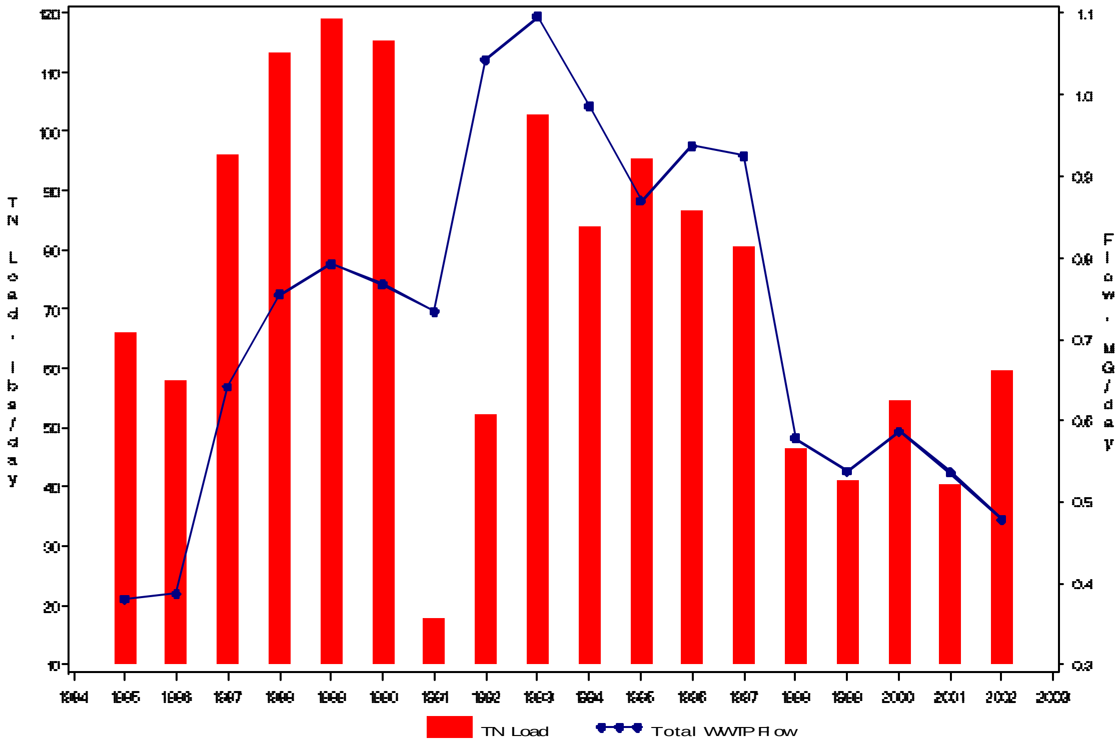
POCOMOKE CITY Wastewater Treatment Plant: Lower Eastern Shore Tributary Strategy Basin
Mean Daily Total Nitrogen Loads and Flow



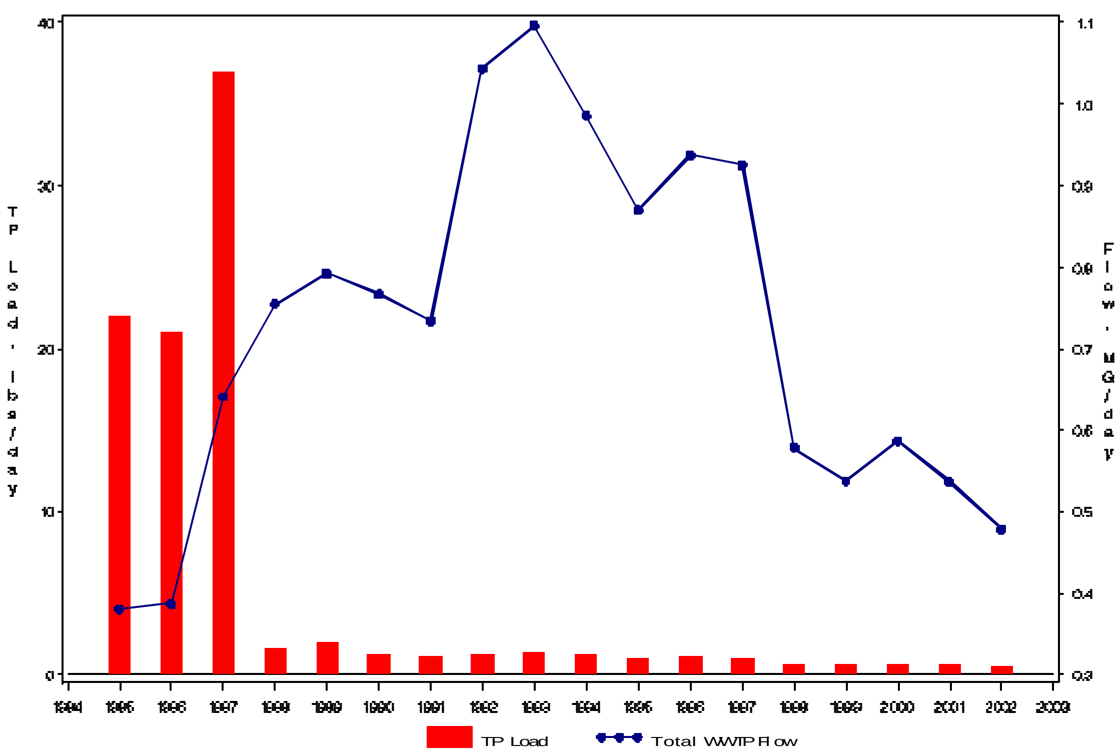
POCOMOKE CITY Wastewater Treatment Plant: Lower Eastern Shore Tributary Strategy Basin
Mean Daily Total Phosphorus Loads and Flow



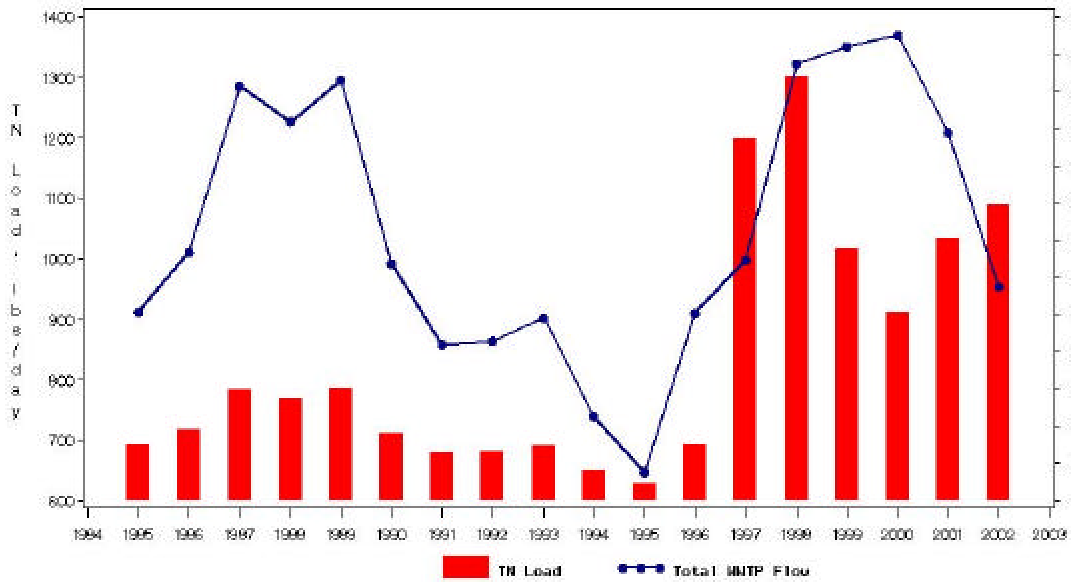
PRINCESS ANNE Wastewater Treatment Plant: Lower Eastern Shore Tributary Strategy Basin
Mean Daily Total Nitrogen Loads and Flow



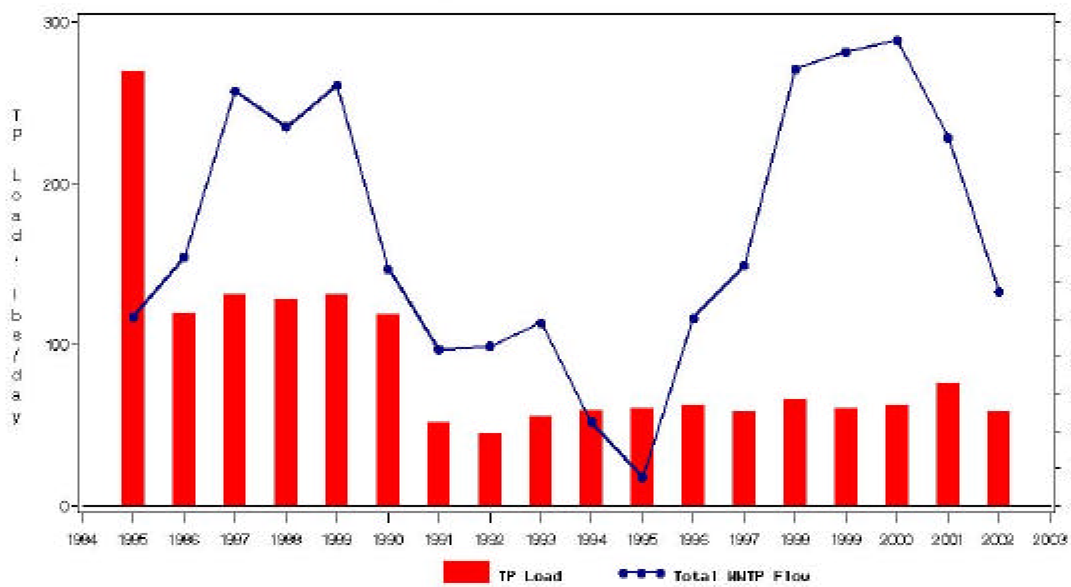
PRINCESS ANNE Wastewater Treatment Plant: Lower Eastern Shore Tributary Strategy Basin
Mean Daily Total Phosphorus Loads and Flow



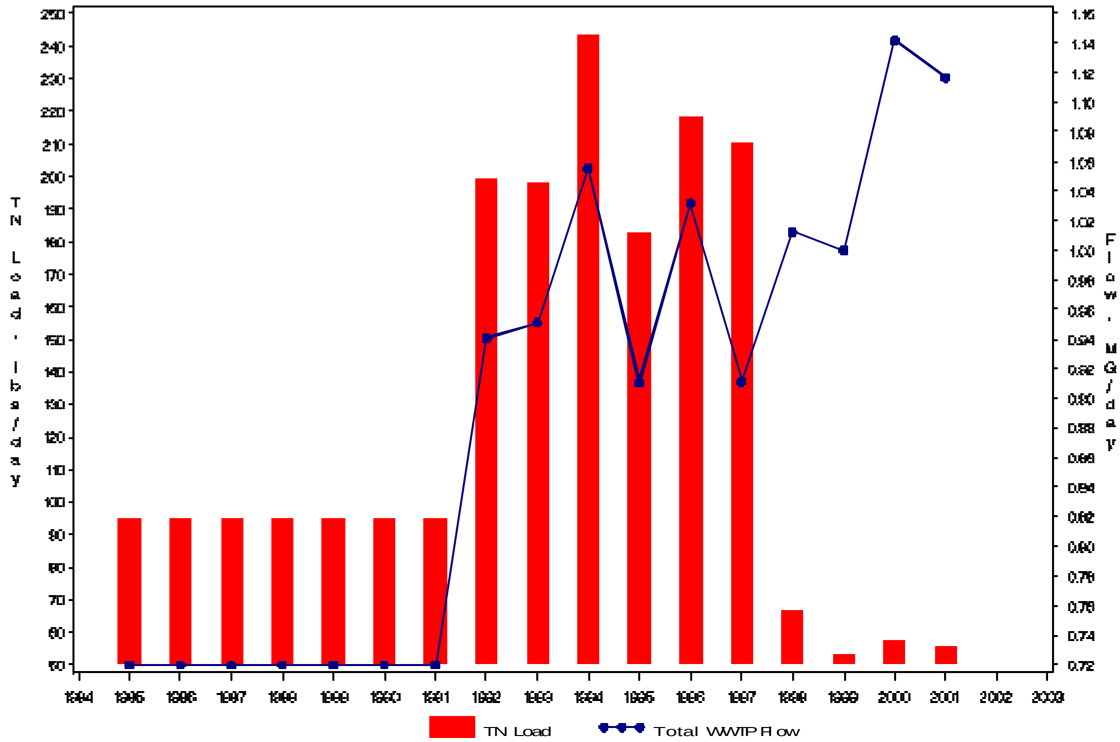
SALISBURY Wastewater Treatment Plant: Lower Eastern Shore Tributary Strategy Basin
Mean Daily Total Nitrogen Loads and Flow



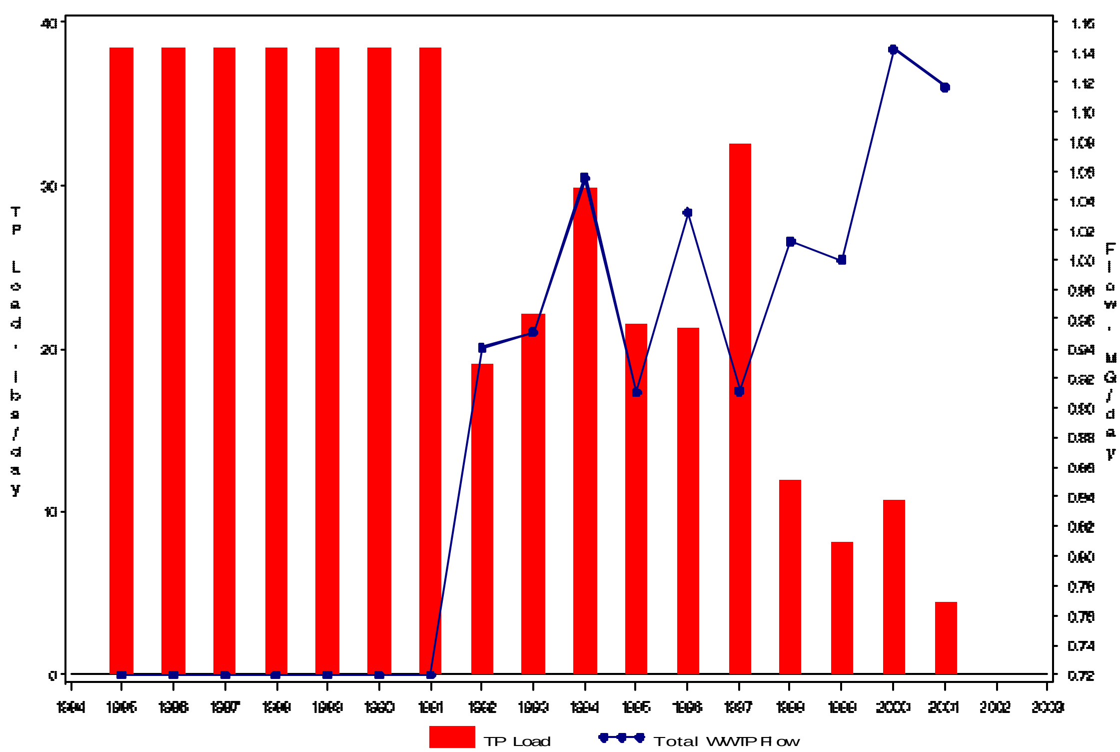
SALISBURY Wastewater Treatment Plant: Lower Eastern Shore Tributary Strategy Basin
Mean Daily Total Phosphorus Loads and Flow



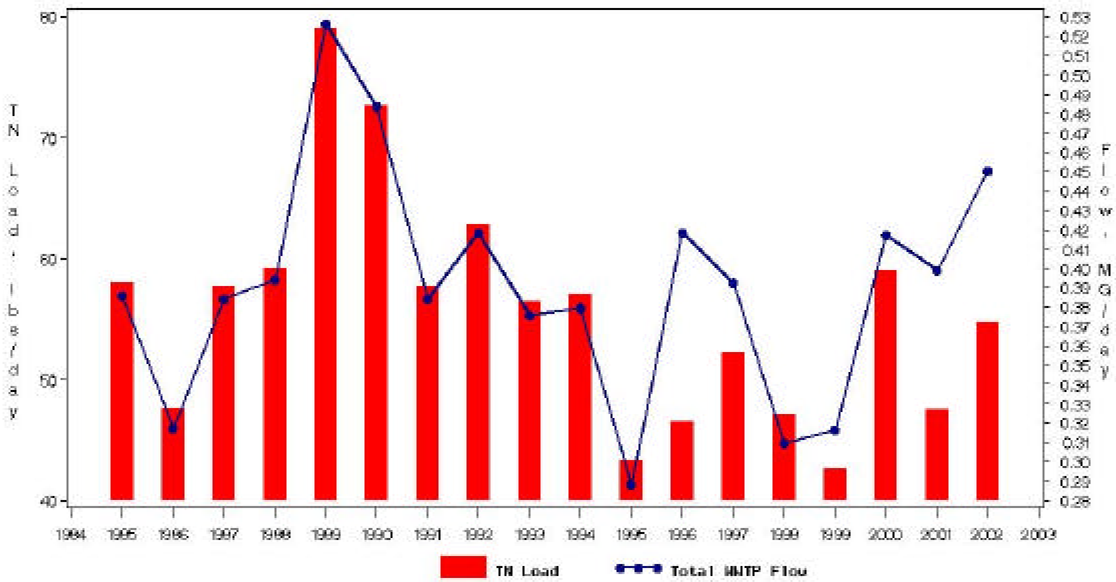
SEAFORD Wastewater Treatment Plant: Lower Eastern Shore Tributary Strategy Basin
Mean Daily Total Nitrogen Loads and Flow



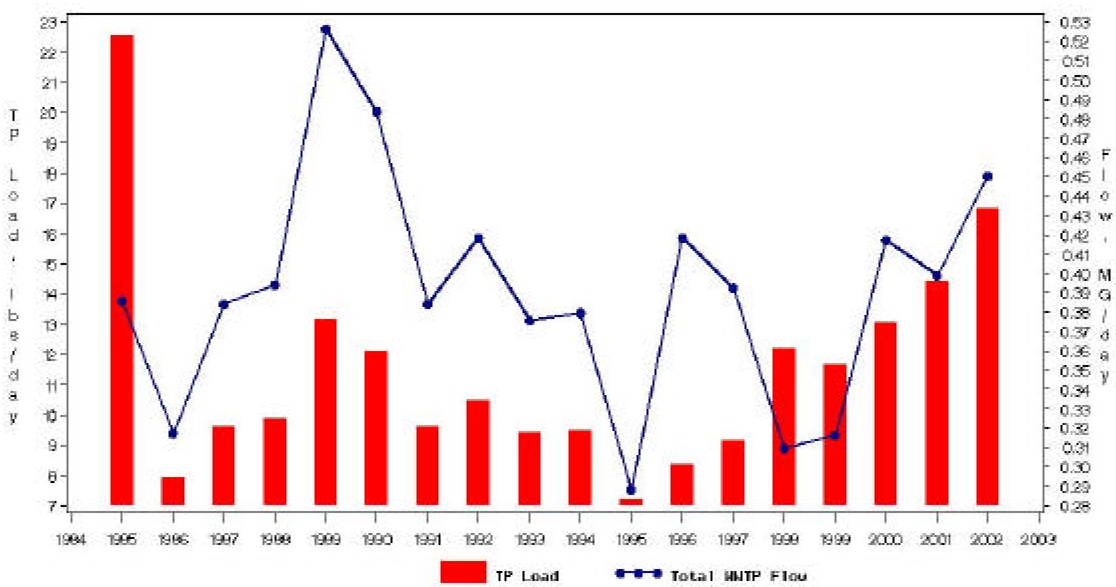
SEAFORD Wastewater Treatment Plant: Lower Eastern Shore Tributary Strategy Basin
Mean Daily Total Phosphorus Loads and Flow



SNOW HILL Wastewater Treatment Plant: Lower Eastern Shore Tributary Strategy Basin
Mean Daily Total Nitrogen Loads and Flow



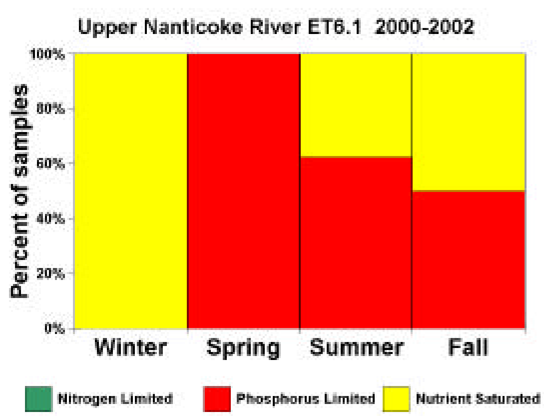
SNOW HILL Wastewater Treatment Plant: Lower Eastern Shore Tributary Strategy Basin
Mean Daily Total Phosphorus Loads and Flow

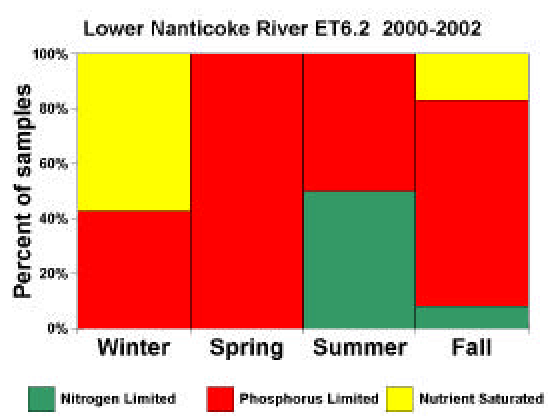


Appendix B – Nutrient Limitation Graphs for the Lower Eastern Shore

The nutrient limitation models were used to predict nutrient limitation for the ten stations in the Lower Eastern Shore. Results are summarized for the most recent three-year period (2000-2002) by season: winter (December-February), spring (March-May), summer (July-September) and fall (October-November). Managers can use these predictions to assess what management approach will be the most effective for controlling excess phytoplankton growth. Interpreting the results can be a little counter-intuitive, however. Remember that nitrogen limited means that *phosphorus* is in excess. Initially, it would seem that the best management strategy would be to reduce phosphorus inputs. However, it may actually be more cost effective to further reduce *nitrogen* inputs to increase the amount of 'unbalance' in the relative proportions of nutrients so that phytoplankton growth is even more limited. When used along with other information available from the water quality and watershed management programs, these predictions will allow managers to make more cost-effective management decisions.

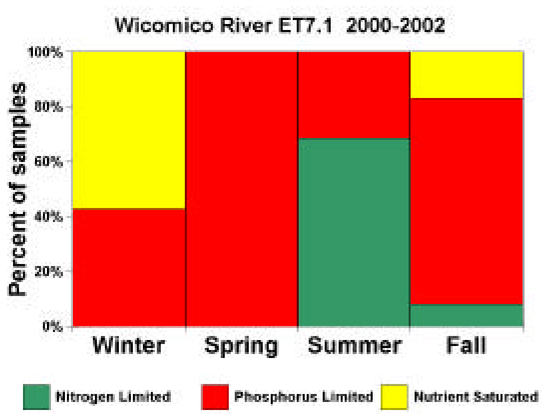
Upper Nanticoke River (ET6.1) - On an annual basis, phytoplankton growth is phosphorus limited about 55 percent of the time and otherwise is nutrient saturated (light limited or no limitation). Winter growth is entirely nutrient saturated; spring growth is entirely phosphorus limited. In the summer and fall, growth is phosphorus limited approximately 65 percent and 45 percent of the time, respectively, and otherwise is nutrient saturated. Total and dissolved inorganic nitrogen concentrations are relatively poor and degrading (increasing). Total and dissolved inorganic phosphorus concentrations are relatively good and total phosphorus concentration is improving (decreasing). The ratio of total nitrogen to total phosphorus ratio is increasing. The dissolved inorganic nitrogen to dissolved inorganic phosphorus ratio suggests that additional phosphorus limitation is possible in the winter with continued decreases in phosphorus concentrations. Nitrogen is greatly in excess relative to phosphorus at this station. Large reductions in nitrogen concentrations are needed to match the reductions in phosphorus and might allow for nitrogen limitation to occur in summer and fall.

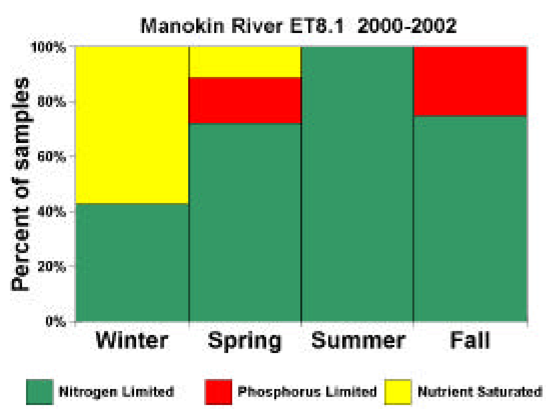




Lower Nanticoke River (ET6.2) - On an annual basis, phytoplankton growth is phosphorus limited approximately 70 percent of the time and nitrogen limited and nutrient saturated (light limited or no limitation) approximately 15 percent of the time each. In the winter, phytoplankton growth is phosphorus limited approximately 40 percent of the time and nutrient saturated approximately 60 percent of the time. In the spring, growth is entirely phosphorus limited. In summer, phytoplankton growth is nitrogen limited 50 percent of the time and phosphorus limited 50 percent of the time. In the fall, phytoplankton growth is phosphorus limited 75 percent of the time and nitrogen limited less than 10 percent of the time. Total and dissolved inorganic nitrogen concentrations are relatively poor; total and dissolved inorganic phosphorus concentrations are relatively fair. Reductions in phosphorus concentrations in the winter and spring and nitrogen concentrations in the summer and fall will help further limit phytoplankton growth in this portion of the Nanticoke.

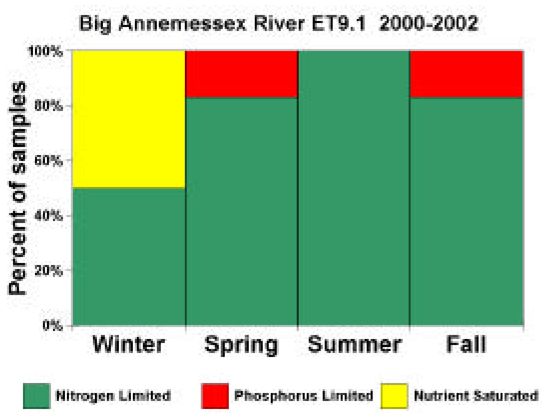
Wicomico River (ET7.1) – On an annual basis, phytoplankton growth is phosphorus limited almost 70 percent of the time and nitrogen limited and nutrient saturated approximately 15 percent of the time each. In the winter, growth is phosphorus limited about 40 percent of the time and otherwise is nutrient saturated. In the spring, growth is entirely phosphorus limited. In summer, phytoplankton growth is nitrogen limited almost 70 percent of the time and phosphorus limited 30 percent of the time. In the fall, phytoplankton growth is phosphorus limited 75 percent of the time and nitrogen limited less than 10 percent of the time. Total and dissolved inorganic nitrogen concentrations are relatively poor but total nitrogen concentration is improving (decreasing). Total and dissolved inorganic phosphorus concentrations are relatively fair and total phosphorus concentration is improving (decreasing). The ratio of total nitrogen to total phosphorus is increasing. Reductions in phosphorus concentrations in the winter and spring and nitrogen concentrations in the summer and fall will help further limit phytoplankton growth in this portion of the Wicomico.

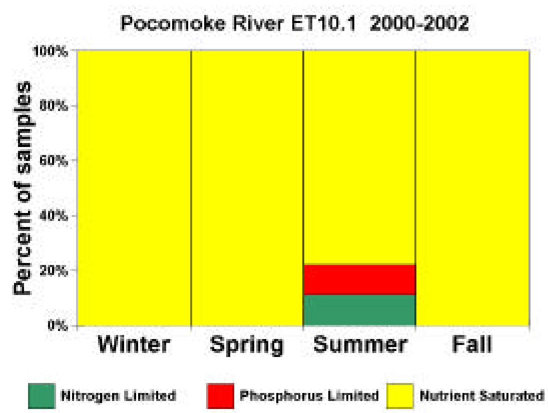




Manokin River (ET8.1) – On an annual basis, phytoplankton growth is nitrogen limited almost 75 percent of the time. In the winter, growth is nitrogen limited about 40 percent of the time and otherwise is nutrient saturated (light limited or no limitation). Growth in spring is nitrogen limited about 70 percent of the time and phosphorus limited about 15 percent of the time. Summer growth is entirely nitrogen limited. In fall, growth is nitrogen limited about 75 percent of the time and phosphorus limited about 25 percent of the time. Total nitrogen and total phosphorus concentrations are both relatively fair, and dissolved inorganic nitrogen and dissolved inorganic phosphorus concentrations are both relatively good. Dissolved organic phosphorus concentration is degrading (increasing). The ratio of dissolved inorganic nitrogen to dissolved inorganic phosphorus is decreasing. Reductions in nitrogen would further limit phytoplankton growth at this station, while reductions in phosphorus will help bring the system into better balance, particularly in the winter and spring.

Big Annemessex (ET9.1) - On an annual basis, phytoplankton growth is nitrogen limited almost 80 percent of the time. Growth is nutrient saturated (light limited or no limitation) about 50 percent of the time in the winter. In the spring and fall, growth is nitrogen limited about 85 percent of the time and phosphorus limited about 15 percent of the time. In the summer, growth is entirely nitrogen limited. Total nitrogen, dissolved inorganic nitrogen, total phosphorus and dissolved inorganic phosphorus concentrations are all relatively good. Dissolved inorganic nitrogen concentration is improving (decreasing). The ratio of dissolved inorganic nitrogen to dissolved inorganic phosphorus is decreasing. Continued reductions in nitrogen would further limit phytoplankton growth at this station, while reductions in phosphorus will help bring the system into better balance, particularly in the winter and spring.

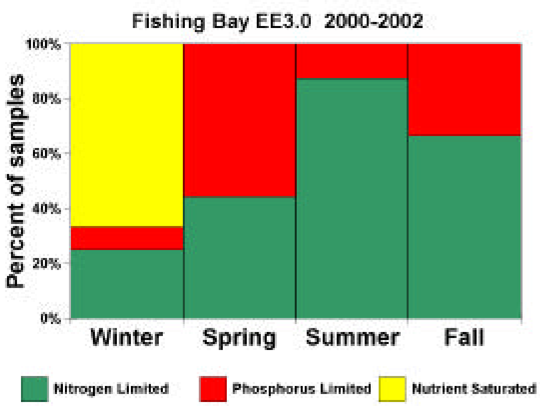


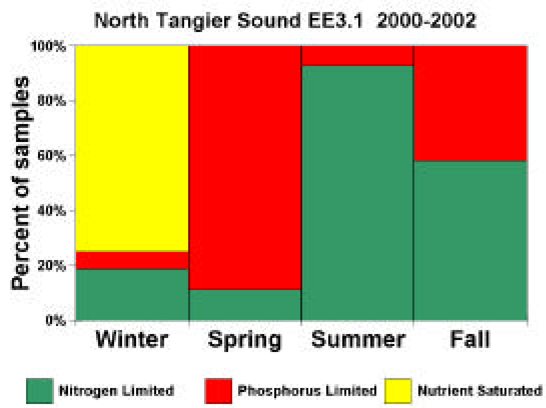


Pocomoke River (ET10.1) – Phytoplankton growth is nutrient saturated (light limited or no limitation) almost 95 percent of the time, with only occasional nitrogen or phosphorus limitation in summer (10 percent of the summer samples each). Total nitrogen, dissolved inorganic nitrogen, total phosphorus and dissolved inorganic phosphorus concentrations are all relatively fair and total nitrogen concentration is improving (decreasing). This is a blackwater system, where light limitation is high due to dark color of the water. The ratio of dissolved inorganic nitrogen to dissolved inorganic phosphorus is decreasing and suggests that continued reductions in nitrogen would increase the occurrences of nitrogen limitation and further limit phytoplankton growth in this portion of the Pocomoke. Reductions in phosphorus will help bring the system into better balance throughout the year.

Embayments

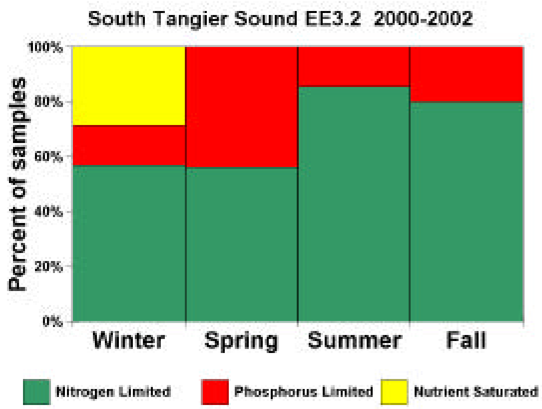
Fishing Bay (EE3.0) – On an annual basis, phytoplankton growth is nitrogen limited more than 55 percent of the time and phosphorus limited almost 30 percent of the time. In the winter, growth is nutrient saturated (light limited or no limitation) about 65 percent of the time, nitrogen limited about 25 percent of the time, and phosphorus limited less than 10 percent of the time. In the spring, phytoplankton growth is phosphorus limited about 55 percent of the time and nitrogen limitation about 45 percent of the time. Summer growth is nitrogen limited more than 85 percent of the time and phosphorus limited about 10 percent of the time. Fall growth is nitrogen limited 65 percent of the time and phosphorus limited the remainder of the time. Total nitrogen and total phosphorus concentrations are both relatively fair; dissolved inorganic nitrogen and dissolved inorganic phosphorus concentrations are relatively good, and dissolved inorganic nitrogen concentration is improving (decreasing). The ratio of dissolved inorganic nitrogen to dissolved inorganic phosphorus is decreasing; this ratio is relatively low (but nitrogen is still in excess), indicating that continued reductions in nitrogen would enhance nitrogen limitation, especially in the spring. Reductions in phosphorus will help bring the system into better balance, particularly in the winter and spring.

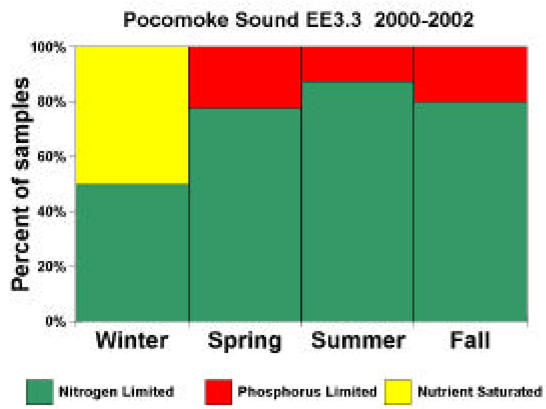




North Tangier Sound (EE3.1) – On an annual basis, phytoplankton growth is nitrogen limited and phosphorus limited about 40 percent of the time each. In the winter, growth is nutrient saturated (light limited or no limitation) about 75 percent of the time, nitrogen limited more than 15 percent of the time and phosphorus limited more than 5 percent of the time. In the spring, phytoplankton growth is phosphorus limited almost 90 percent of the time and nitrogen limited about 10 percent of the time. Summer growth is nitrogen limited more than 90 percent of the time and otherwise is phosphorus limited. Fall growth is nitrogen limited almost 60 percent of the time and is otherwise phosphorus limited. Total nitrogen concentration is relatively fair and dissolved inorganic nitrogen, total phosphorus and dissolved inorganic phosphorus concentrations are all relatively good. Total phosphorus and dissolved inorganic nitrogen concentrations are improving (decreasing). Continued reductions in nitrogen would further limit phytoplankton growth at this station in the summer and fall. Continued reductions in phosphorus will help bring the system into better balance and will increase the occurrence of phosphorus limitation in the winter and spring.

South Tangier Sound (EE3.2) – On an annual basis, phytoplankton growth is nitrogen limited about 70 percent of the time and phosphorus limited almost 25 percent of the time. In the winter, growth is nitrogen limited 55 percent of the time, phosphorus limited 15 percent of the time, and nutrient saturated 30 percent of the time. In the spring, summer and fall, growth is nitrogen limited 55 percent, 85 percent and 80 percent of the time of the time, respectively and is otherwise phosphorus limited. Total nitrogen, dissolved inorganic nitrogen, total phosphorus and dissolved inorganic phosphorus concentrations are all relatively good; dissolved inorganic nitrogen concentration is improving (decreasing). The ratio of dissolved inorganic nitrogen to dissolved inorganic phosphorus is decreasing; this ratio is relatively very low, consistent with the strong nitrogen limitation at this station. Continued reductions in nitrogen would further limit phytoplankton growth at this station throughout the year. Reductions in phosphorus will help bring the system into better balance and will increase the occurrence of phosphorus limitation in the winter and spring.





Pocomoke Sound (EE3.3) – On an annual basis, phytoplankton growth is nitrogen limited almost 80 percent of the time. Winter growth is nitrogen limited 50 percent of the time and nutrient saturated (light limited or no limitation) the rest of the time. Spring, summer and fall growth is nitrogen limited almost 80 percent, almost 90 percent and 80 percent of the time, respectively, and otherwise is phosphorus limited. Total nitrogen and total phosphorus concentrations are relatively fair; dissolved inorganic nitrogen and dissolved inorganic phosphorus concentrations are relatively good and dissolved inorganic nitrogen concentration is improving (decreasing). The ratio of dissolved inorganic nitrogen to dissolved inorganic phosphorus ratio is decreasing; this ratio is relatively very low, consistent with the strong nitrogen limitation at this station. Continued reductions in nitrogen would further limit phytoplankton growth at this station throughout the year. Reductions in phosphorus will help bring the system into better balance and will increase the occurrence of phosphorus limitation in the winter and spring.

Appendix C – References

Agresti, A. and B. Caffo. 2000. Simple and effective confidence intervals for proportions and differences of proportions result from adding two successes and two failures. The American Statistician 54:280–288.

Alden, R. W., III, D. M. Dauer, J. A. Ranasinghe, L. C. Scott, and R. J. Llansó. 2002. Statistical Verification of the Chesapeake Bay Benthic Index of Biotic Integrity. Environmetrics, In Press.

Fisher, T. R. and A. B. Gustafson. 2002. Maryland Department of Natural Resources Chesapeake Bay Water Quality Monitoring Program—Nutrient/Bioassay Component—Covering the Period August 1990 – December 2001—May 2002 Report.

Ranasinghe, J. A., L. C. Scott, R. C. Newport, and S. B. Weisberg. 1994. Chesapeake Bay Water Quality Monitoring Program, Long-term Benthic Monitoring and Assessment Component, Level I Comprehensive Report, July 1984-December 1993. Chapter 5: Baltimore Harbor Trends. Prepared for Maryland Department of Natural Resources, Tidewater Ecosystem Assessments, by Versar, Inc., Columbia, Maryland.

Scott, L. C., J. A. Ranasinghe, A. T. Shaughnessy, J. Gerritsen, T. A. Tornatore, and R. Newport. 1991. Long-term benthic Monitoring and Assessment Program for the Maryland Portion of Chesapeake Bay: Level I Comprehensive Report (July 1984-April 1991), Volume I – Text. Prepared for Maryland Department of Natural Resources, Tidewater Ecosystem Assessments, by Versar, Inc., Columbia, Maryland.

Van Belle, G. and J. P. Hughes. 1984. Nonparametric tests for trend in water quality. Water Resources Research 20:127-136.

Weisberg, S. B., J. A. Ranasinghe, D. M. Dauer, L. C. Schaffner, R. J. Diaz, and J. B. Frithsen. 1997. An Estuarine Benthic Index of Biotic Integrity (B-IBI) for the Chesapeake Bay. Estuaries 20:149–158.